

CALIFORNIA AGRICULTURAL EXPERIMENT STATION

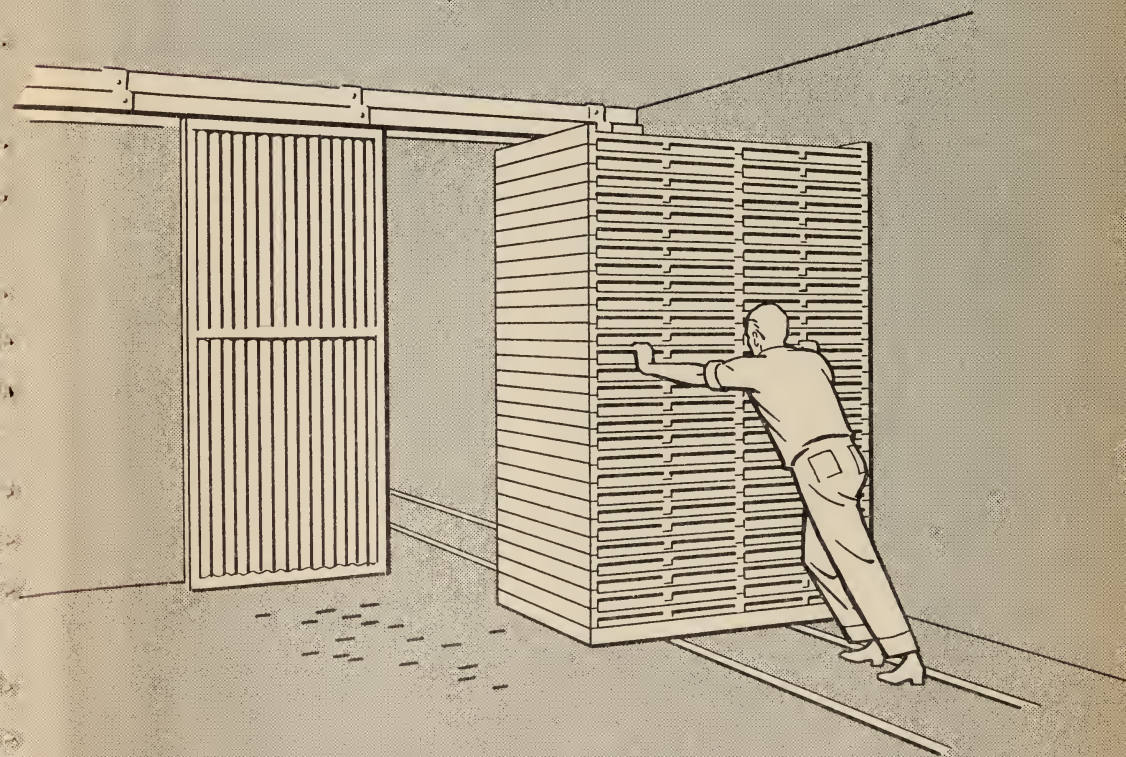
FRUIT DEHYDRATION

I. Principles and Equipment

R. L. PERRY, E. M. MRAK, H. J. PHAFF,
G. L. MARSH, and C. D. FISHER

December, 1946

Bulletin 698



THE COLLEGE OF AGRICULTURE
UNIVERSITY OF CALIFORNIA • BERKELEY

CONTENTS

| | PAGE |
|---|------|
| Introduction | 3 |
| History of dehydration | 3 |
| Statistics | 5 |
| Advantages | 8 |
| Limitations | 8 |
| Principles of pretreatment | 10 |
| Condition of raw material | 10 |
| Harvesting | 11 |
| Storage of fresh fruit | 11 |
| Washing fruit prior to drying | 12 |
| Spray-residue removal | 12 |
| Sorting and trimming | 13 |
| Cutting, pitting, and peeling | 14 |
| Treatment of pits and waste materials | 14 |
| Dipping | 16 |
| Blanching | 17 |
| Sulfuring | 22 |
| Preparation equipment | 23 |
| Plant layout | 23 |
| Fruit boxes | 26 |
| Cutting tables | 26 |
| Blanchers | 26 |
| Boilers | 28 |
| Fruit washers | 29 |
| Washers and materials for spray-residue removal | 29 |
| Peeling, pitting, and cutting machines | 31 |
| Miscellaneous small equipment | 31 |
| Tray and box washers | 32 |
| Skin-checking equipment | 32 |
| Sulfuring houses and burners | 33 |
| Principles relating to dehydration | 35 |
| Process of evaporation | 35 |
| Moisture in fruit | 37 |
| Properties of air-vapor mixtures | 38 |
| Measuring air conditions | 39 |
| The psychrometric chart | 40 |
| Recirculation | 43 |
| Drying rates and drying times | 44 |
| Fruit temperatures during dehydration | 47 |
| Air flow | 47 |
| Air pressures and friction losses | 48 |
| Power required to move air | 51 |
| Drying equipment | 51 |
| Evaporators | 51 |
| Dehydraters | 52 |
| Countercurrent dehydraters | 53 |
| Cross-flow dehydraters | 54 |
| Center-inlet dehydraters | 56 |
| Center-exhaust or two-stage dehydraters | 56 |
| Cabinet dehydraters | 56 |
| Conveyor dehydraters | 56 |
| Vacuum dehydraters | 57 |
| Drum driers | 57 |
| Furnaces | 57 |
| Fans | 60 |
| Tunnel dehydrater operation | 62 |

FRUIT DEHYDRATION: I. PRINCIPLES AND EQUIPMENT^{1, 2}

R. L. PERRY,³ E. M. MRAK,⁴ H. J. PHAFF,⁵ K. L. MARSH,⁶
AND C. D. FISHER⁷

INTRODUCTION

History of Dehydration.—Fruits have been preserved by drying since the dawn of history, but the use of dehydration⁸ for this purpose is a recent development. In California, mechanical driers made their first appearance in the Nineteenth Century. At the beginning of the fruit-drying industry mostly natural-draft evaporators⁹ were used; later, forced-draft evaporators were introduced. The use of forced draft was an improvement, although all of the early driers were inefficient and frequently difficult to operate satisfactorily. The characteristics and operating procedures of these driers are described in publications by Cruess (1919a),¹⁰ Cruess, Christie, and Flossfeder (1920), Caldwell (1923), and Wiegand (1924).

Except for the drying of apples and hops, natural-draft evaporators are not now used extensively in California. Until 1919, sun-drying was favored for prunes and other fruits. In the prune-drying season of September, 1918, however, heavy rains caused severe losses to many growers. Most of the trays of fruit were stacked, but many were wet before they were stacked. After five days of rainy weather, many of the prunes became so moldy that little could be done to save them. Sulfuring was suggested as a means of retarding spoilage; this procedure was rejected, however, because there is no trade demand for sulfured prunes. Cruess (1919a, 1921) stressed the importance of dehydration and advised its use as an insurance against rain damage. Fortunately, the forced-draft dehydrator was developed and marketed in ample time to satisfy the subsequent demand for an efficient drier. According to Christie

¹ Received for publication August 9, 1945.

² This bulletin presents the principles and operations of dehydration; specific directions for the dehydration of cut fruits and of whole fruits will be covered in separate publications.

³ Associate Professor of Agricultural Engineering and Agricultural Engineer in the Experiment Station.

⁴ Associate Professor of Food Technology and Associate Mycologist in the Experiment Station.

⁵ Instructor of Food Technology and Assistant Microbiologist in the Experiment Station.

⁶ Assistant Professor of Food Technology and Assistant Chemist in the Experiment Station.

⁷ Chief Chemist, Dried Fruit Association of California.

⁸ The term *dehydration*, as used in this publication, refers to the process of drying in a dehydrator. A *dehydrator* is a mechanical drier equipped to control temperature, air flow, and humidity. The operator of a dehydrator is called a *dehydrator*. Fruit dried in a dehydrator is termed *dehydrated fruit*, in contrast to *sun-dried fruit*, which is dried in the sun, and *evaporated fruit*, which is dried in an evaporator.

⁹ An *evaporator* is a natural-draft drier equipped with artificial heat. Evaporators which are equipped with forced draft, but which do not offer recirculation are termed *air-blast* evaporators.

¹⁰ See "Literature Cited," at the end of this bulletin, for complete data on citations, which are referred to in the text by author and date.

(1923), the use of dehydraters for the drying of prunes increased rapidly after 1918. At present over three quarters of the California prune crop is dehydrated.

Grape dehydration began as a means of salvaging raisins when sun-drying conditions were unfavorable, but it assumed new importance as a means of preserving wine grapes in the years following the adoption of the Eighteenth Amendment. Wine grapes were later handled by other methods, and interest in grape dehydration declined until about 1925. In that year, a new type of raisin—the golden-bleached Thompson—was introduced as a competitor of the commercially known, light-colored Smyrna raisin. Prior to World War II, approximately 25,000 tons of golden-bleached raisins were produced per year, but, because of loss of export markets, production was curtailed in 1940 and 1941. In 1942, however, production was again increased, this time to meet the need of converting a greater percentage of grapes into raisins. In 1943 the War Food Administration required the drying of practically all raisin grapes. To aid producers in meeting this requirement the Administration sponsored the construction of a number of dehydraters. This spurred the industry to a record production in 1943 of 40,000 tons of golden-bleached and 10,000 tons of Valencia-type Muscat raisins. In 1944 and 1945, however, golden-bleached fell to about 28,000 tons and Valencias, because of almost no demand, to about 800 tons.

In 1931, low prices for canning clingstone peaches stimulated a demand for their dehydration. Maximum production—about 50,000 tons of fresh peaches, or about 6,500 tons of dry—was reached in 1936. Since then, production has varied with cannery demands and with prices for the fresh fruits. Phaff, Mrak, *et al.* (1945) have described the manufacture of blanched dehydrated clingstone peaches. This new product, first made on a small scale in 1943, was produced later for use primarily by the armed forces.

A limited tonnage of dehydrated, unsulfured cut fruits has been prepared for sale in "health-food" stores and for use in the manufacture of baby foods. This fruit, however, because of its undesirable appearance and flavor, has not been widely accepted. In California in the past, practically all sulfured cut fruits, with the exception of apples, were dried in the sun. Occasionally, the drying of partially sun-dried fruit has been completed in a dehydrater. At present, however, there is considerable interest in drying cut fruits entirely in dehydraters.

During the past few years, there has been an increasing tendency to dehydrate figs as a means of eliminating the hazard of rain damage and of releasing drying-yard space for other purposes. A large proportion of the crop, however, while on the trees or the ground, prior to harvesting, and while on trays in the drying yard, is still dried in the sun.

Since the beginning of World War II, there has been an increasing production of dehydrated cranberries and blueberries for use as sauce and in bakery products. Other small fruits, such as huckleberries, have been dried on only an experimental scale, in most instances; this production has been described by Friar and Mrak (1943). Consideration has been given to the possibility of drying guavas for later use in jams and jellies. Dehydrated sulfured bananas from Mexico have made their appearance on American markets.

Statistics.—In California, fruit drying is an industry of considerable importance; indeed, a large proportion of the many kinds of fruits in this state is grown for this specific purpose. The principal important exceptions are pears and clingstone peaches. Some fruits, notably Royal or Blenheim apricots, can be used interchangeably for fresh shipment, canning, freezing, and drying. In some districts the selling of unblemished and well-formed apricots to canneries, and drying of the remainder of the crop has become common practice. Certain varieties of apricots, especially Moorpark and Hemskirke, are seldom canned or sold fresh, but are grown almost exclusively for drying. Tiltons are usually dried, but are also canned or sold fresh in some regions of the state.

Muir and Lovell peaches are used largely for drying, whereas the Elberta and J. H. Hale varieties, although sometimes dried, are planted chiefly for fresh shipment. During the last few years there has been an increase in the canning of Lovell, Elberta, and J. H. Hale freestone peaches. In addition a small tonnage is frozen each year. Raisin grapes may be dried, sold to wineries, shipped fresh, or, less frequently, canned. Figs, for the most part, are dried or shipped fresh; only one variety—the Kadota—is canned. In California prunes are grown almost entirely for drying, although in some districts Sugar prunes are shipped fresh.

Cherries are seldom dried; they are produced primarily for fresh shipment, canning, freezing, and sulfiting. In California the Black Tartarian, Bing, Lambert, and Black Republican varieties are produced almost entirely for shipping. The Royal Anne (Napoleon) variety, on the contrary, is used for canning and sulfiting, as well as for shipping fresh. Sour cherries, which are not commercially important in California, are almost exclusively canned or frozen for subsequent use by bakeries. About 50 to 60 per cent of the California apple crop is utilized fresh. The remainder, especially the lower grades, is canned, dried, or made into juice. Other fruits, such as berries, persimmons, and plums are seldom dried.

The principal drying localities, seasons, varieties, yields, and over-all drying ratios¹¹ of fruits dried commercially are given in table 1. The yields and over-all drying ratios vary with the variety and locality, as well as from year to year. These variations make extremely difficult the deriving of reliable average drying ratios for the various fruits; therefore, only the ranges are given in this bulletin.

The tonnages of the most important dried fruits produced in California, as compiled by Shear (1943), are given in table 2. More than half of this fruit is still dried in the sun. Although the dehydration of fruits has been increasing from year to year, this increase has been restricted mostly to large producers of dried prunes, raisins, or figs. Small producers, because of the high initial cost of plant construction, did not find dehydration economically feasible in the past, for, until recently, there have been no dehydrater designs suitable

¹¹ The term *over-all drying ratio* refers to the number of pounds of fresh fruit required to produce 1 lb. of dried fruit. For example, if 6 lbs. of fresh apricots yield 1 lb. of dried apricots, the over-all drying ratio is 6 to 1 (often expressed 6 : 1). In contrast to the over-all drying ratio, the actual drying ratio refers to the pounds of prepared fresh fruit to yield 1 lb. of dried fruit. For example, if 4 lbs. of apricot halves are required to produce 1 lb. of dried apricots, the actual drying ratio is 4:1.

TABLE 1

LOCALITIES, VARIETIES, SEASONS, YIELDS, AND RANGE OF DRYING RATIOS FOR DRIED FRUITS IN CALIFORNIA*

| Fruit | Principal localities | Principal varieties | Drying season* | Yield per acre in dried tons* | | | Range of drying ratios* |
|---------------------------------------|--|--|--------------------------|-------------------------------|--------|------|-------------------------|
| | | | | Low | Medium | High | |
| Apples | Humboldt, Mendocino, Monterey, Santa Cruz, and Sonoma counties | Baldwin..... | Sept. 1 to Oct. 1..... | 1.3 | 2.0 | 2.8 | 7.0:1 to 7.5:1 |
| | | Bellflower..... | Sept. 1 to Oct. 1..... | 3.0 | 3.5 | 4.0 | 7.5:1 to 8.0:1 |
| | | Delicious..... | Oct. 1 to Oct. 20..... | 1.0 | 1.4 | 2.2 | 7.0:1 to 7.5:1 |
| | | Gravenstein..... | July 20 to Sept. 15..... | 0.5 | 1.5 | 2.5 | 7.5:1 to 8.5:1 |
| | | Hoover..... | Oct. 1 to Oct. 15..... | 1.5 | 2.0 | 3.3 | 7.0:1 to 7.5:1 |
| | | Jonathan..... | Sept. 15 to Oct. 15..... | 0.7 | 1.5 | 2.0 | 7.0:1 to 8.0:1 |
| | | King..... | Sept. 1 to Oct. 1..... | 1.0 | 2.0 | 2.8 | 7.0:1 to 7.5:1 |
| | | Yellow Newtown..... | Sept. 15 to Dec. 1..... | 1.0 | 2.0 | 2.8 | 7.0:1 to 7.5:1 |
| | | Permain..... | Oct. 1 to Oct. 15..... | 0.4 | 0.7 | 1.0 | 7.0:1 to 7.5:1 |
| | | Rhode Island Greening..... | Oct. 1 to Oct. 15..... | 0.5 | 1.5 | 2.5 | 7.5:1 to 8.5:1 |
| | | Rome Beauty..... | Oct. 15 to Nov. 15..... | 1.3 | 2.5 | 3.3 | 7.0:1 to 8.0:1 |
| | | Wagener..... | Oct. 15 to Nov. 1..... | 0.5 | 1.5 | 2.5 | 7.5:1 to 8.0:1 |
| | | Winesap..... | Oct. 15 to Nov. 1..... | 0.5 | 1.5 | 2.5 | 7.5:1 to 8.0:1 |
| Apricots | Santa Clara, Sacramento, and San Joaquin valleys | Blenheim, Royal, Tilton..... | June 15 to Aug. 1..... | 0.5 | 1.0 | 2.5 | 4.0:1 to 7.5:1 |
| Figs | San Joaquin Valley | Adriatic..... | July 20 to Nov. 1..... | 0.5 | 1.5 | 2.5 |† |
| | | Black Mission..... | July 20 to Nov. 1..... | 1.5 | 2.0 | 3.0 |† |
| | | Calimyrna..... | July 20 to Nov. 1..... | 0.5 | 1.0 | 2.0 |† |
| | | Kadota..... | July 20 to Nov. 1..... | 0.5 | 1.5 | 2.5 |† |
| Nectarines | Sacramento and San Joaquin valleys | Hardwick, Newboy, Quetta, Stanwick..... | July 15 to Aug. 30..... | 0.5 | 1.5 | 3.0 | 5.5:1 to 8.5:1 |
| Peaches (clingstone) | Sacramento and San Joaquin valleys | Midsummer varieties and Phillips cling..... | Aug. 1 to Sept. 15..... | 0.5 | 1.0 | 2.0 | 6.5:1 to 10.0:1 |
| Peaches (freestone) | Sacramento and San Joaquin valleys | Elberta, Lovell, Muir..... | July 15 to Sept. 15..... | 1.0 | 2.0 | 4.5 | 4.0:1 to 8.0:1 |
| Pears | Lake and Mendocino counties; Napa, Sacramento, Santa Clara, and Sonoma valleys | Bartlett..... | July 15 to Oct. 1..... | 0.5 | 1.5 | 3.0 | 4.0:1 to 7.0:1 |
| Prunes | Napa, Santa Clara, Sonoma, Sacramento, and San Joaquin valleys | French, Imperial, Sugar, Robe de Sergeant..... | Aug. 15 to Oct. 1..... | 1.0 | 2.0 | 5.0 | 2.0:1 to 3.5:1 |
| Raisins (golden bleached, dehydrated) | San Joaquin Valley | Thompson Seedless..... | Aug. 1 to Oct. 1..... | 1.0 | 1.5 | 3.0 | 3.0:1 to 5.0:1 |
| Raisins (Valencia type, dehydrated) | San Joaquin Valley | Muscat..... | Aug. 15 to Nov. 1..... | 0.5 | 1.0 | 2.0 | 3.0:1 to 5.0:1 |
| Currants (Zante) | San Joaquin Valley | Black Corinth..... | Aug. 5 to Aug. 20..... | 0.5 | 1.5 | 2.5 | 4.0:1 to 6.0:1 |

* The drying season, yield per acre, and drying ratio may vary considerably with the year and locality of production.

† Most of the fig drying usually occurs before the fruit is harvested. For the conversion of dried weights into green weights a drying ratio of 3:1 is commonly used, and for converting dried weights into fruit weights as harvested, 1.5:1 is sometimes used.

for use on small farms. Farm dehydraters are described in this bulletin in the section on dehydration equipment.

Table 3 shows the percentages by uses of harvested California fruits for the years 1934-1938, as compiled by Shear (1943). Slightly over half the deciduous-tree fruits produced in California are dried, and the rest are either canned, frozen, or used fresh.

TABLE 2
TONNAGES OF DRIED-FRUIT PRODUCTION IN CALIFORNIA, FIVE-YEAR AVERAGES,
1894-1938, AND ANNUAL, 1932-1945*
(Unprocessed dry weight)

| Crop year | Apples | Apricots | Figs† | Peaches | Pears | Prunes | Raisins and other dried grapes‡ |
|----------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------------------------------|
| Averages: | <i>tons</i> | <i>tons</i> | <i>tons</i> | <i>tons</i> | <i>tons</i> | <i>tons</i> | <i>tons</i> |
| 1894-1898..... | 2,200 | 8,400 | 1,500 | 10,900 | 3,500 | 35,300 | 43,700 |
| 1899-1903..... | 3,200 | 11,400 | 3,100 | 18,500 | 3,700 | 73,200 | 46,800 |
| 1904-1908..... | 2,600 | 6,700 | 3,300 | 15,500 | 1,600 | 54,600 | 55,000 |
| 1909-1913..... | 3,000 | 14,100 | 4,700 | 23,100 | 1,400 | 72,100 | 71,000 |
| 1914-1918..... | 5,600 | 16,300 | 8,500 | 31,700 | 1,100 | 76,200 | 136,200 |
| 1919-1923..... | 9,000 | 16,500 | 10,900 | 27,000 | 3,100 | 115,500 | 206,300 |
| 1924-1928..... | 9,800 | 20,000 | 10,600 | 22,900 | 4,000 | 176,400 | 242,900 |
| 1929-1933..... | 10,700 | 31,200 | 19,100 | 21,700 | 5,100 | 185,600 | 211,900 |
| 1934-1938..... | 10,500 | 26,200 | 25,500 | 23,400 | 5,800 | 212,200 | 220,400 |
| Annual: | | | | | | | |
| 1932..... | 9,800 | 35,300 | 19,000 | 22,200 | 5,500 | 168,000 | 265,500 |
| 1933..... | 13,300 | 37,500 | 21,500 | 23,400 | 7,000 | 182,000 | 198,200 |
| 1934..... | 8,800 | 16,800 | 23,500 | 25,800 | 4,900 | 171,000 | 173,800 |
| 1935..... | 12,500 | 25,800 | 24,000 | 19,500 | 6,100 | 258,000 | 204,000 |
| 1936..... | 11,700 | 32,200 | 20,000 | 26,400 | 8,100 | 159,000 | 183,400 |
| 1937..... | 12,000 | 34,400 | 28,700 | 23,000 | 3,500 | 249,000 | 248,000 |
| 1938..... | 7,500 | 21,500 | 31,500 | 22,200 | 6,500 | 224,000 | 292,000 |
| 1939..... | 10,900 | 41,000 | 26,900 | 24,900 | 8,100 | 185,000 | 247,020 |
| 1940..... | 4,800 | 11,300 | 32,000 | 24,400 | 3,100 | 175,000 | 172,200 |
| 1941..... | 8,500 | 19,700 | 33,500 | 14,900 | 3,600 | 178,000 | 210,000 |
| 1942..... | 6,700 | 20,800 | 28,200 | 23,400 | 2,600 | 171,000 | 255,000 |
| 1943..... | 8,900 | 6,600 | 36,700 | 16,400 | 3,700 | 196,000 | 401,500 |
| 1944..... | 5,200 | 25,700 | 35,200 | 26,700 | 3,300 | 159,000 | 309,500 |
| 1945§..... | 8,800 | 8,200 | 31,700 | 22,500 | 4,900 | 231,000 | 249,000 |

* After Shear, S. W. Deciduous fruit statistics as of January, 1943. Contribution from the Giannini Foundation of Agric. Econ. Rept. 83. (Mimeo.)

† Includes merchantable and nonmerchantable figs.

‡ Dried grapes other than raisins are included from 1936 to date.

§ Preliminary estimates.

Preservation by drying effects a great saving in shipping weight and volume, as well as in manpower. These factors are important. Table 4 shows comparative equivalent weights and volumes of fruit packed for shipment in the fresh, canned, and dried form, based on 1 ton of fresh fruit.

Most of the dehydraters in California are located in the prune and seedless-grape areas, particularly in the San Joaquin, Sacramento, and Santa Clara valleys and in Napa and Sonoma counties. Because a large proportion of the deciduous fruits is grown in these areas, it is possible in most instances to use existing dehydration plants for the drying of other fruits. Maps of the distribution of various fruit crops in California are given in Crawford and Hurd (1941). Evaporaters are located principally in Napa, Sonoma, and Santa Cruz counties—the important apple-producing areas. These evapora-

ters are not suitable for other fruits, although floor-kiln evaporaters can be used for hops.

In the Pacific Northwest, prunes are dried by dehydration, and apples largely by evaporation, although all new plants are dehydraters. Evaporaters are also used for the drying of apples in New York and in other eastern states. Sun-drying, however, is primarily a California practice.

Advantages.—Several advantages favor dehydration as a method of drying. Fruit drying on trays in the sun is susceptible to insect infestation, contamination with microörganisms which may cause molding and fermentation, contamination with dust and dirt, and damage caused by rain and by animals. This type of drying is usually slow, causing great losses in sulfur dioxide in sulfured fruits. Dehydration, if properly controlled, not only protects against all of these hazards but also produces clean fruit of higher quality. The percentage of sulfur dioxide retained during dehydration is, on an average, three to four times as high as that during sun-drying. Dehydration is preferable to evaporation because it more accurately controls temperature, air flow, and humidity. Some evidence indicates that a slightly better yield of prunes can be obtained by dehydrating than by sun-drying. Dehydration releases the sun-drying field for the growing of crops or for other uses, increases the turnover of trays so that fewer are needed, and saves in drying-yard labor.

Limitations.—Certain fruits cannot be dehydrated very successfully. Imperial prunes and some plums tend to crack and bleed; in this way they lose weight and become sticky. Until recently, cut fruits, with the exception of apples, when dried entirely in a dehydrater, were off-color and unacceptable to the trade. In order to avoid off-color in the fruit, it was necessary to expose the freshly sulfured fruit to the sun for several hours before dehydration. Not only is this procedure expensive and troublesome, but, in addition, the advantages of cleanliness and freedom from insect infestation offered by dehydration are partially lost. The pretreatment of cut fruits before dehydration requires the services of more workers than may be available.

The inefficient or improper operation of dehydraters may be costly, or may give rise to an inferior product through case hardening, bleeding, scorching, or smudging.

In certain years, variation in the fruit or rapid drying at low humidity may cause the outside of the fruit to dry more rapidly than the moisture can diffuse to the surface from the interior flesh. This condition results in the formation of a hard, overdried layer on the surface, although the interior may be underdried. This type of uneven drying is termed "case hardening." In storage, case-hardened fruit is likely to undergo fermentation when the entrapped moisture diffuses to the surface. In 1939, because of case hardening caused by improper dehydrater operation, certain growers were compelled to dehydrate their prunes two or even three times. Failure to control humidities, a tendency to use excessively high temperatures, and periodic variations in the composition and structure of the fruit are the main causes of case hardening.

The use of excessively high temperatures to accelerate drying may cause scorching, with an accompanying decrease in quality and, possibly, a loss in weight. The use of low-grade fuels, or inefficient burners, or direct heat from

TABLE 3
USES OF CALIFORNIA FRUITS, AVERAGE CROP YEARS, 1934-1938*

| Kind of fruit | Dried | Canned | Otherwise processed | Used fresh |
|----------------------------|-----------------|-----------------|---------------------|-----------------|
| | <i>per cent</i> | <i>per cent</i> | <i>per cent</i> | <i>per cent</i> |
| Total, listed..... | 33.0 | 7.7 | 20.5 | 38.8 |
| Deciduous tree..... | 54.6 | 21.7 | 1.1 | 22.6 |
| Grapes..... | 41.3 | 0.2 | 45.0 | 13.5 |
| Citrus..... | 0.0 | 2.0 | 11.0 | 87.0 |
| Deciduous tree, total..... | 54.6 | 21.7 | 1.1 | 22.6 |
| Apples..... | 35.2 | 0.2 | 7.2 | 57.4 |
| Peaches..... | 28.9 | 55.1 | 0.0 | 16.0 |
| Pears..... | 14.6 | 29.9 | 0.0 | 55.5 |
| Prunes..... | 100.0 | | 0.0 | 0.0 |
| Apricots..... | 66.5 | 25.2 | 0.0 | 8.3 |
| Plums..... | 0.0 | 3.0 | 0.0 | 97.0 |
| Cherries..... | 0.0 | 16.7 | 28.9 | 54.4 |
| Figs..... | 87.9 | 5.8 | 0.0 | 6.3 |
| Grapes, total..... | 41.3 | 0.2 | 45.0 | 13.5 |
| Wine..... | 0.0† | 0.0 | 100.0† | 0.0 |
| Table..... | 9.0† | 0.0 | 46.3† | 53.7 |
| Raisin..... | 73.6 | 0.3 | 18.8 | 7.3 |
| Citrus, total..... | 0.0 | 2.0 | 11.0 | 87.0 |
| Oranges..... | 0.0 | 1.8 | 9.4 | 88.8 |
| Grapefruit..... | 0.0 | † | 6.3 | 93.7 |
| Lemons..... | 0.0 | 3.2 | 17.8 | 79.0 |

* Compiled from data by: S. W. Shear. Deciduous fruit statistics as of January, 1943. Contribution from the Giannini Foundation of Agric. Econ. Rept. 83. (Mimeo.)

† Dried table and wine varieties included in "otherwise processed" as mostly used for wine and juice ultimately.

‡ Assumed to be zero.

TABLE 4
COMPARATIVE EQUIVALENT WEIGHTS AND VOLUMES OF FRUIT PACKED FOR SHIPMENT, IN FRESH, CANNED, AND DRIED FORM, BASED ON ONE TON OF FRESH FRUIT

| Fruit | Fresh fruit | | Canned fruit* | | Dried fruit,† bulk pack | |
|------------------------|---------------|----------------|---------------|----------------|-------------------------|----------------|
| | Weight | Volume | Weight | Volume | Weight | Volume |
| | <i>pounds</i> | <i>cu. ft.</i> | <i>pounds</i> | <i>cu. ft.</i> | <i>pounds</i> | <i>cu. ft.</i> |
| Apples..... | 2,240‡ | 61.5 | 2,460 | 49.0 | 232 | 6.9 |
| Apricots..... | 2,380§ | 51.0 | 3,300 | 65.5 | 408 | 9.0 |
| Freestone peaches..... | 2,310§ | 56.0 | 2,400 | 48.0 | 373 | 8.3 |
| Pears..... | 2,240§ | 46.0 | 2,400 | 48.0 | 373 | 9.5 |
| Prunes..... | 2,420§ | 45.0 | | | 800 | 15.9 |
| Seedless raisins..... | 2,320§ | 45.0 | 3,300 | 60.0 | 580 | 14.1 |

* Weights and volumes given for cases of No. 2½ cans.

† Weights and volumes given for 25-pound bulk-pack boxes.

‡ Standard apple boxes.

§ Standard lugs for the fruit.

oil burners may result in a deposit of soot and smoke particles on the fruit. Although this deposit is not readily observable on prunes, it does have an adverse effect on their quality—especially on their flavor.

In order to secure the best results, conscientious and well-trained operators are needed. Readings of wet- and dry-bulb temperatures should be taken, and

examination of the drying fruit made at frequent intervals. Unfortunately, dehydraters are sometimes operated in a manner so careless that damage to the quality of the product results.

Neither sun-dried nor dehydrated fruits reconstitute, or rehydrate, in the ratio to which they dry. This is unfortunate, since the consumer usually does not consider the losses in preparation, nor realize the actual volume of fresh fruit represented by the reconstituted dried product. In some instances prolonged periods of soaking are required in reconstituting the dried fruit to the maximum and desired volume. As an example, dehydrated clingstone peaches should be soaked 12 to 16 hours before cooking. If the peaches are cooked without soaking, their volume may be less than half that obtained by cooking after soaking. The time required for soaking and cooking is considerably reduced if, in the drying process, the fruit is blanched before sulfuring.

In many instances the term "dehydrated" to the consumer implies that dehydrated food is actually imperishable. This is an unfortunate misconception, because dehydrated foods are perishable and must be handled accordingly. During storage, dehydrated fruits are susceptible to insect infestation, microbiological deterioration, and chemical changes. These destructive processes not only affect the appearance of the fruit, but cause changes in taste and nutritive values.

PRINCIPLES OF PRETREATMENT

The preparation procedures to which the fruit is subjected before dehydration are known collectively as *pretreatment*.

Condition of Raw Material.—The quality of the final product reflects the condition of the fruit at the time of dehydration. What is accomplished in washing, spray-residue removal, and trimming may well determine the final grade and whether the dried product conforms with the requirements of the Food and Drug Administration. Peeling, cutting, lye-dipping, sulfuring, and blanching affect the drying characteristics, vitamin retention, cooking qualities, edibility, and storage characteristics, as well as the quality grade of the finished product. Inadequate or faulty preparation may mean the difference between profit and loss.

The production of dried fruits of high quality necessitates the use of proper cultural practices, maturity standards, and harvesting methods. Cultural practices are discussed fully in other publications by Allen (1937), Condit (1941), Davis and Tufts (1941), Hendrickson (1937), Howard (1943), Jacob (1940), Philp and Davis (1946), Veihmeyer and Hendrickson (1943), and others.

As a rule, fruits to be dehydrated should be fully mature and in firm-ripe condition. Immature fruits should not be dehydrated; they result in a product poor in color and flavor, and have a high shrinkage ratio. Great care should be taken to avoid injury to the fresh fruit during packing and subsequent handling.

Apricots or peaches to be blanched before dehydration must be firm—never mushy ripe—in order to avoid slabbing and to prevent excessive losses from bleeding. Bartlett pears are picked while hard ripe. The pears are then allowed to ripen in boxes while in storage. Ripening may be hastened by the use of

ethylene gas or by storing mature pears near immature ones. Maturity can be determined by a pressure tester, as described by Davis and Tufts (1941), with the pressure test reading not over 19 pounds.

For best quality and greater yield, raisin grapes should not be picked for drying until the Balling, or Brix degree (approximate sugar percentage determined by the use of a hydrometer) of the juice reaches 23; grapes allowed to attain 24 to 26° Balling yield even better raisins; (see Jacob, 1942 and 1944). In rainy and cool seasons, however, this range is sometimes difficult or even impossible to attain. In event of rain, grapes comparatively low in sugar may have to be dehydrated in order to salvage the crop, but they should attain at least a 21° Balling before drying.

Cherries and berries should be picked when table ripe. Plums can be handled more easily if they are on the firm-ripe side of maturity and are allowed to finish ripening in boxes. Figs usually dry to a considerable extent on the tree before they drop and harden. Prunes, too, late in the season in certain areas, often dry partially on the tree or on the ground. Persimmons may be firm when harvested, but should be fully ripened before drying to avoid excessive puckery taste.

Harvesting.—As a rule, figs and prunes drop to the ground when they are ready for drying. In the Sacramento and San Joaquin valleys, however, prunes often remain on the tree even after they are fully mature, and it is necessary to knock them from the trees with poles. Although the harvesting of apricots and peaches can be done at lower cost per ton by shaking the fruit to the ground or on sheets of canvas, the quality always suffers because: first, in falling the fruit becomes bruised or dirty, or both; and second, immature fruit is always mixed with mature. Shaking should be done only for figs and prunes. All other fruits should be picked by hand from the tree or vine in order to secure the best quality.

Storage of Fresh Fruit.—Mature fruit should be dried as soon as possible after it has reached maturity. If it must be held for more than 1 or 2 days it should be placed in cold storage. Some fruits cannot withstand the temperature in warm weather for more than a day without showing bruises or molding. In cool weather firm-ripe fruit may well stand 2 or 3 days of storage at room temperature. Crafts and Brooks¹² have observed and pointed out that apricots showing a slightly green cast will ripen evenly, though slowly, in cold storage or more rapidly at room temperature. Spoilage losses, however, may be very high in years of serious brown-rot infection. One successful grower in the Santa Clara Valley prolongs his drying season several days by holding firm-ripe apricots, of canning quality, in cold storage.

Prunes are ordinarily considered capable of withstanding considerable abuse, but in humid seasons they will mold in the boxes if allowed to stand several days after picking. Moldy fruit should not be dried, even though an alkaline dip removes the obvious evidence of mold.

Freestone peaches do not keep well in cold storage; they should be dehydrated as soon as possible after they are harvested. Firm clingstone peaches may be held, in carefully operated cold-storage warehouses, in reasonably good condition for several days, and apples and pears for considerably longer.

¹² Crafts, A. S., and R. Brooks. Unpublished data.

For details concerning correct handling practices, storage temperatures, and humidities for fresh fruits see Rose, Wright, and Whiteman (1941).

Washing Fruit Prior to Drying.—All fruits should be washed, but it is particularly important that ones picked from the ground should be thoroughly washed to remove adhering bits of soil, straw, and other foreign material. Prunes and grapes are washed at the time of dipping; apples and pears are rather effectively washed during the process of spray-residue removal; in addition, pears are (or at least should be) washed after cutting and traying. Whatever the fruit, washing should be thorough and should be conducted in such a manner as to avoid recontamination of the fruit with dirt and microorganisms.

The cleaning of prunes is frequently unsatisfactory, particularly where alkaline dips are no longer used for checking the skin. Frequently, where washers employing recirculation are used, a given volume of cold or warm water is sprayed over the fruit many times a day. After several hours' use this water becomes quite muddy and, in some instances, so dirty that the dried fruit actually shows dirty splotches. Recirculation is not recommended, but if unavoidable it must be carried out in a manner that will not impair the washing process. The latter can be done by applying an effective cold fresh-water spray after the initial washing. This will remove dirty water which remains after the first spray.

Prunes washed properly before dehydration need no further washing after drying, if other handling equipment is kept clean. Under current practices, however, washing is nearly always necessary before dehydrated prunes are packed. Even though most foreign material may be removed easily, dehydrators find it very difficult to remove from fresh prunes adhering particles of leaves and stems. These can be removed by means of a leaf and trash remover, which is equipped with a blower and an efficient slotted screen shaker. In addition, foreign objects and decomposed prunes should be removed at a sorting belt.

Pears should be washed after cutting to remove adhering particles of dirt and evidences of insect infestation. As the trays are removed from the cutting tables, they should be sprayed with cold water. Figs are usually not washed before drying, because they are washed effectively at time of packing. Nevertheless, it would be a desirable practice to wash figs before dehydration. After lye-dipping, grapes are usually washed in a spray shaker or in an immersion-type washer. Clingstone peaches must be thoroughly washed after lye-peeling. It is not customary to wash freestone peaches and apricots. These soft fruits, when allowed to stand with free moisture on the surface, may undergo rapid deterioration through growth of the brown-rot fungus. Cutters also object to handling wet fruit, because it reduces their output considerably.

Spray-Residue Removal.—Some spray materials leave residues on the fruit which, above certain quantities, are considered injurious to human health. Although the extent of the hazard in spray residues is not always measurable, the greatest danger to the consumer is in chronic rather than acute poisoning.

The health hazard of arsenic- and lead-spray residues has been strongly voiced by Geiger, Becker, and Crowley (1936) and Hanzlik (1937). Cardiff (1937), on the contrary, has argued strongly against the possible dangers of

ingesting spray residues. Fairhall and Neal (1938) fed two human subjects 100 milligrams of lead arsenate over a period of 10 days, during which time they were on a controlled diet. The degree of absorption, path of excretion, and toxicity of this dosage were evaluated. Fairhall and Neal observed that "While the lead arsenate was completely broken down in the body, no untoward effects on the well-being of these two individuals attributable to this quantity were noted. The greater part of the lead and arsenic derived from the ingested lead arsenate was directly recovered, and it was found that the lead was excreted with the feces and that the arsenic was excreted in the urine."

Laws exist—and are enforced—which limit the amounts of arsenic, lead, or fluorine that may remain on or in foods offered for sale for human use. Definite limits, or "tolerances," for these spray residues have been established by the Food and Drug Administration of the Federal Security Agency. In 1940 the Agency announced that the tolerance for lead and arsenic had been liberalized because of the experimental results obtained by the United States Public Health Service. The new tolerances, as of August 10, 1940, are: 0.025 grain arsenic as arsenic trioxide per pound (3.58 mg. per kilogram) and 0.05 grain of lead per pound (7.15 mg. per kilogram). Fluorine was not included in the study made; consequently, the tolerance remains at 0.02 grain of fluorine per pound (2.86 mg. per kilogram) as of November 14, 1938. These limits apply to both fresh and dried fruits. The tolerances for spray residues are changed from time to time. Growers uncertain of current tolerances should obtain this information from the Federal Security Agency, Washington, D. C., or from the Federal Food and Drug Administration, Federal Building, San Francisco, California.

There is greater necessity for removing spray residues from unpeeled fruit that is to be dried than from fruit that is to be consumed fresh. This is true, because during drying the percentage of residue increases proportionately to the drying ratio, and the Food and Drug Administration tolerance does not differentiate between fresh and dried fruit. In order to cope with this problem, the fruit should be washed before drying, and the use of toxic insecticides should be avoided for as long as possible before harvesting. These procedures are discussed more fully in publications by Allen (1937), Hough (1936), Haller, Smith, and Ryall (1935), Robinson and Hatch (1933 and 1935), Overly, St. John, *et al.* (1933), and Hartman (1929). Hoffman (1937) has discussed the removal of spray residues from cherries.

Apples and pears, which are the most important fruits from the standpoint of methods for spray-residue removal, are discussed on page 29 of this bulletin.

Sorting and Trimming.—As a rule, to harvest cull fruit for drying is inadvisable and uneconomical; nevertheless, it is frequently done. Neither immature, moldy, or heavily infested fruits, nor those imbedded with dirt should be harvested. Since pickers and cutters are usually paid by the box or by some other unit of volume or weight, however, it is unsatisfactory to depend on their sorting the fresh fruit. Sorting may be done as a separate operation before cutting or dipping. If defective parts of individual fruits are small, they may be trimmed out and disposed of with the culls. Trimmings and cull fruit should be collected in a separate box, in order to avoid soiling the good fruit,

or, in the instance of apricots, contaminating the pits which have commercial value. Because of its sugar content, waste fruit may have value as a source of alcohol manufacture.

Cutting, Pitting, and Peeling.—Fruits are cut, pitted, or peeled to facilitate drying and to produce dried fruit of better appearance and eating quality.

Apricots and freestone varieties of peaches and nectarines are halved and pitted, but are not peeled in commercial practice. These fruits are cut by hand knife around the suture, the halves separated, and the pit removed. On a few occasions some freestone peaches have been peeled by hand after sulfuring; this practice loosens the skin of mature fruit to such an extent that it can be removed without the use of a knife. This process, however, has never been found feasible because it is too costly. Cutting these fruits into smaller pieces—such as slices—facilitates drying, but offers difficulties in handling after drying because the fruit sticks to the trays. Occasionally apricots have been dried whole, but usually only after dipping them in lye and exposing them to prolonged sulfuring.

Clingstone varieties of peaches and nectarines are cut around the suture, but require the use of a pitting spoon to remove the pit, which adheres to the flesh. In large establishments mechanical pitters, such as those described by Cruess (1938), are used. A superior product is obtained when cling peaches are lye-peeled after pitting. However, they may be dehydrated without being peeled. The quality of the dehydrated unpeeled peach is comparatively poor and there is relatively little demand for it. Peeling is accomplished by immersing the halved peaches in a hot 1.0 to 2.5 per cent lye solution for 30 to 60 seconds, then by washing in sprays of cold water.

Apples are peeled and cored by machine. Since they are extremely susceptible to enzymatic browning, they are then immersed in a dilute sodium chloride (salt) or bisulfite solution to prevent initial discoloration. After apples are hand-trimmed to remove blemishes or pieces of skin, they are mechanically cut into rings, quarters, or smaller sections; preferably, they should be dipped again in a dilute bisulfite solution. The peels, cores, and trimmings amount to about 20 to 30 per cent or more of the fresh apple weight.

Pears are stemmed and halved and the calyx is removed by hand or mechanical operations. It is not customary to peel, remove the core, or cut pears into thin slices, although these procedures do offer certain advantages. Sliced pears dry more rapidly than do half pears, but are rather difficult to remove from the trays. Pears that are peeled and cored before drying are more attractive, but these operations involve additional labor costs and loss in weight.

Persimmons are cut into halves, quarters, sixteenths, or slices and may or may not be peeled. Cranberries are pulped or sliced before drying. Grapes, figs, prunes, berries, and other small fruits are dried whole and without peeling. Grapes are lye-dipped and usually sulfured.

Equipment such as the cutting shed, cutting tables, and pit boxes has been described in detail by Mrak and Long (1941).

Treatment of Pits and Waste Materials.—Apricot pits should be collected in clean containers; they should never be mixed with trimmings or with decomposed fruit. The pits are dried in the sun by spreading them about 4 inches deep on trays or on concrete drying surfaces, where they are periodically

stirred by raking (see fig. 1). Apricot pits should not be sulfured, because this reduces their value, and the pits from sulfured whole fruit should never be mixed with unsulfured pits. The pits are sold to by-product plants where they are cracked and the kernels separated by brine flotation. The kernels are utilized in the production of sweet oil and of bitter-almond oil for the candy and bakery trades. The shells, after being pulverized, are used in several industrial applications, principally as a filler for plastic and rubber products.

Peach pits are principally used in the production of charcoal to be mixed with chicken feeds, but are also used for other purposes. Activated carbon

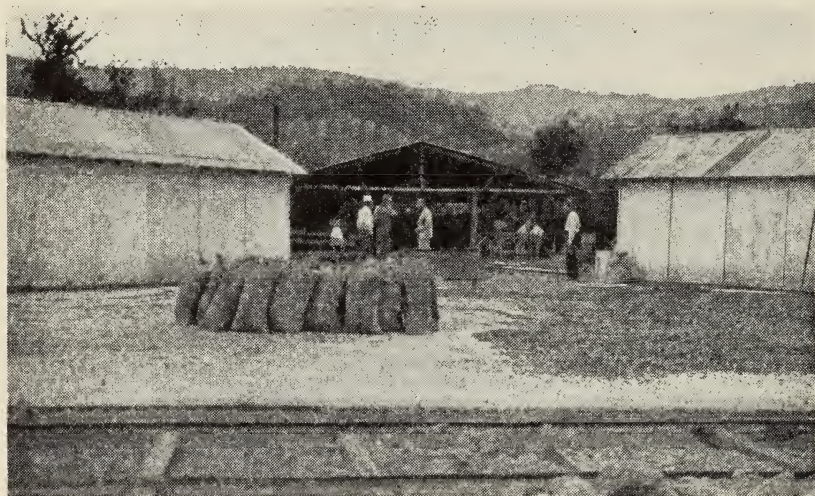


Fig. 1.—Apricot pits spread on concrete surface for drying in the sun prior to sacking.

made from peach pits for gas masks compares unfavorably with that made from other sources, for example, cocoanut shells. At one time, peach pits were subjected to a destructive distillation to recover methyl alcohol, acetic acid, pyroligneous acid, and other chemicals. But, as more efficient competitive processes have changed economic and market conditions, most of the destructive distillation plants have discontinued operation except for the production of charcoal.

Apple peelings and cores are utilized largely for making industrial alcohol, apple brandy, or cider vinegar. Much of the press-cake pomace is dried and sold as stock feed or for the manufacture of pectin.

Pear trimmings and rotten fruit have no commercial value at present. They do have some feeding value for hogs, however, if fed with grain and other dry feed. This waste fruit is an excellent breeding source for insects which may later damage the dried fruit; it should not be dumped near the cutting shed. In order to eliminate this hazard, the waste material should be spread thinly for rapid drying; or, if it is placed in holes or in piles, sufficient lye, quicklime, or chlorinated lime should be added to prevent fermentation, and resultant odors. The drying yard should always be kept free of such refuse in order to reduce insect infestation and to promote cleanliness.

Prior to the war, canners dried cherry stems to be sold in Europe for use in pharmaceutical preparations and as flavoring for liqueurs. Table 5 gives the types and percentages of waste of a number of fruits.

Dipping.—Certain fruits are treated in an alkaline bath in order to remove from the skin the waxy coating termed the “bloom,” or to induce the formation of many minute skin cracks, called “checks,” to facilitate drying. This may be accomplished by submersion or by passing the fruit under a spray of the hot alkaline solution. Many producers have found, however, that checking

TABLE 5
TYPE AND PERCENTAGES OF WASTE IN PREPARING VARIOUS
FRUITS FOR DEHYDRATION

| Fruit | Type of waste | Amount of waste |
|---------------------------|--|--------------------|
| | | <i>per cent</i> |
| Apples..... | Peelings and cores..... | 20-30 |
| Apricots..... | Pits..... | 6-10 |
| Bananas..... | Skins..... | 45-50 |
| Cherries..... | Stems and pit if pitted..... | 8-20 |
| Figs..... | Only culls..... | |
| Guavas..... | Seeds..... | 20-45 |
| Grapes..... | Only culls..... | |
| Nectarines..... | Pits..... | 9-14 |
| Peaches (clingstone)..... | Pits..... | 11-15 |
| | Skins..... | 10-15 |
| Peaches (freestone)..... | Pits..... | 4-8 |
| Pears..... | Stems and calyx ends..... | 1-3 |
| Persimmons..... | Stems and skins..... | 25-35 |
| Pineapples..... | Crown, shell, and cores: Crown removed..... | 35-45 |
| | Crown present..... | 45-55 |
| Pomegranates..... | Skins and sector tissues..... | 50-60 |
| Prunes..... | Only culls..... | |

causes the prunes to bleed or juice badly during dehydration, and, as a result, have resorted to cold- or hot-water washes instead of the alkali treatment. Hot water not only removes the bloom, but also reduces or eliminates bleeding. Cruess (1943) has reported, however, that the drying time increases when lye is omitted.

In the production of golden-bleached raisins, Thompson Seedless grapes are treated with a $\frac{1}{4}$ to $\frac{1}{2}$ per cent hot lye solution for 5 to 15 seconds before sulfuring. By this procedure, the skins are checked and the bloom is removed. After the dipping and washing process, the checked areas tend to discolor rapidly. Hussein, Mrak, and Cruess (1942) found that the oxidase activity of these grapes was stimulated by a 5-second dip in hot lye but was greatly reduced when the dip was extended to 30 seconds. The behavior of the enzyme was similar when hot water was used as a dipping bath. If in the latter type of bath the temperature of the water was lowered from 205° F to 180° more than twice as long a time was required to reach the same degree of inactivation. Unfortunately, the longer dip cannot be used on Thompson Seedless grapes because it results in overchecking and mushiness of the fruit. Furthermore, any discoloration resulting from oxidase activity in Thompson Seedless grapes bleaches out during sulfuring and leaves no noticeable effect on the final dried product.

Muscat grapes are sometimes dipped in a lye or carbonate solution before dehydration. The skin is not checked, but the waxy bloom is removed. The finished product is known as the Valencia raisin.

It is advisable to lye-dip sweet cherries to be dried whole, but not sour varieties, which should always be pitted.

Blanching.—Apricots, peaches, pears, and nectarines are usually sun-dried. Characteristically, the dried product is translucent, somewhat glossy, and is of good color and texture. Fruit sulfured and then dehydrated without other pretreatment is ordinarily opaque and dull in appearance, less uniform in color, and of tougher texture. Because of these differences, dehydrated cut fruits, with the exception of apples, have been placed in lower quality grades. It has long been known that the commercially acceptable appearance of sun-dried fruits can be attained by exposing freshly sulfured halves to the sun for 3 to 4 hours before dehydration. This process, however, has all the disadvantages of sun-drying.

It would seem that a rational basis for dried-cut-fruit standards would give greatest weight to such factors as nutritive value and sanitation. These factors, however, have been almost completely ignored by the trade, which substitutes appearance for food value. Appearance has been the primary trade requirement for dried fruit for such a long time that a new product, whether or not it rates higher in all other respects, must resemble an older product to be acceptable. A dehydrated fruit, therefore, must meet the trade requirements for appearance.

Mrak, Phaff, *et al.* (1943) have pointed out that the approved appearance of sun-dried cut fruit can be obtained in the dehydrater by using ultraviolet rays. They were able to demonstrate this experimentally by exposing cut sulfured fruit to an H-5 (G.E.) lamp for 2 hours before dehydration. They also showed that steam-blanching, correctly applied to cut fruits, likewise yields a dehydrated product which resembles sun-dried fruits in appearance.

Nichols and Christie (1930) called attention to the fact that steam-blanching shortens the drying time. They did not recommend it, however, for with the short blanching times used in their experiments they failed to realize its possibilities. When longer blanching times were tried (Mrak, Phaff, *et al.*, 1943) this method was found to produce dehydrated cut fruit similar in color and appearance to the sun-dried product.

To date, this required appearance of dehydrated fruits can be obtained only by the two preliminary treatments described above. Of the two, blanching appears to be the most workable and practical.

Fruit removed from cold storage should attain room temperature before it is cut. Cold fruit causes excessive condensation of the steam and increases blanching costs. Apricots, in particular, may slab and stick to the trays.

Blanching is best accomplished by exposing fruit spread on dehydrater trays to steam at atmospheric pressure. This can be done in continuous or discontinuous cabinet blanchers. The time of blanching will vary with the size, variety, and maturity of fruit, the efficiency of the blancher, the characteristics of the trays, and the extent of continued heat penetration into the fruit after stacking of the trays. Phaff, Perry, and Mrak (1945) pointed out that the temperatures attained and maintained in different parts of fruit pieces should

be known if the blanching process is to be understood thoroughly. When a cut fruit half—a freestone peach for example—is exposed to steam at atmospheric pressure, the surface temperature at once rises very rapidly, as shown in figure 2, then gradually approaches steam temperature. In the center of the fruit piece the temperature does not change at first; but it begins to rise slowly and then more rapidly as it follows the surface temperatures. Small fruits heat through more quickly, but about 11 minutes are needed to heat the centers of

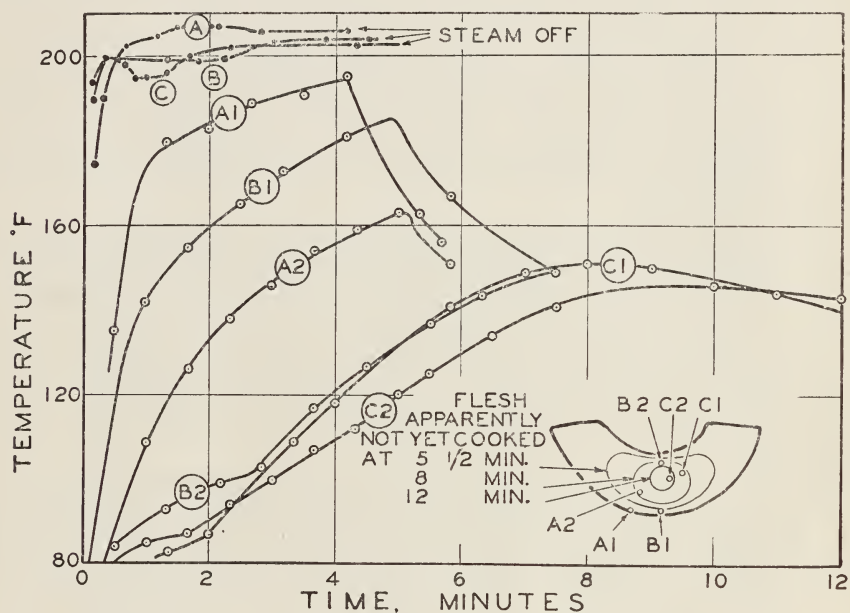


Fig. 2.—Temperatures in a laboratory blancher, and in freestone peach halves during blanching. Curves A, B, and C, blancher temperatures for runs 1, 2, and 3, respectively. Curves A1 and A2, B1 and B2, and C1 and C2, peach flesh temperatures for runs 1, 2, and 3, respectively. Positions at which peach flesh temperatures were measured are indicated in the sketch at the lower right.

larger peaches to above 200° F. When trays are removed from the blancher the surface temperature of the fruit begins to drop almost at once, if heat can escape readily from the stack, while the center temperature drops more slowly. Since the center was slower in heating, with its temperature better maintained on cooling, the blanching effect on the fruit is quite even.

Each operator must learn to determine the proper degree of heat penetration in order to avoid over- or underblanching. The cut fruit should be heated more than two thirds of the way through by the time it emerges from the blancher. The extent of heat penetration can be determined visually by cutting apricots, freestone peaches, pears, or nectarines with a knife, or by testing for the enzyme peroxidase¹³ on the cross section (see figs. 3 and 4). The cutting

¹³ The test for peroxidase is made as follows: the cut cross section is flooded with a 0.1 per cent alcoholic solution of guaiacol or benzidine. A few drops of a 0.3 per cent hydrogen peroxide solution is then applied to the surface. In a few minutes any area where the enzyme peroxidase has not been heat-inactivated will turn brownish if guaiacol is used or dark blue if benzidine is used.

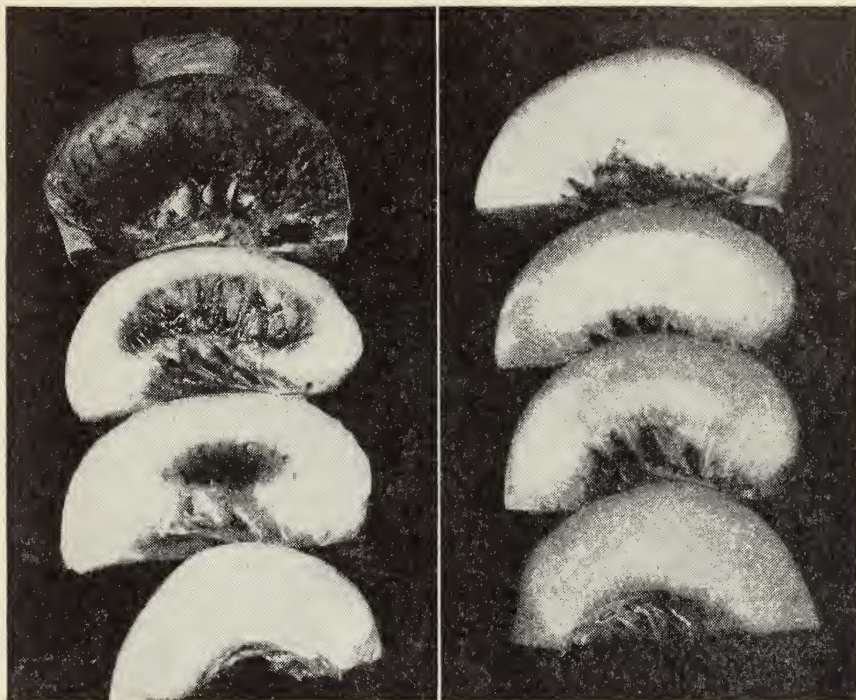


Fig. 3.—Appearance of sections of freestone peach halves blanched in steam for various periods of time. Blanching times were, from top to bottom, 0, 3, 6, and 9 minutes. Sections at the left were flooded with guaiacol and hydrogen peroxide, whereas those at the right were not. Dark-colored areas at the left and light-colored areas at the right indicate underblanching. (From *Food Industries*, vol. 15, no. 4, p. 59.)

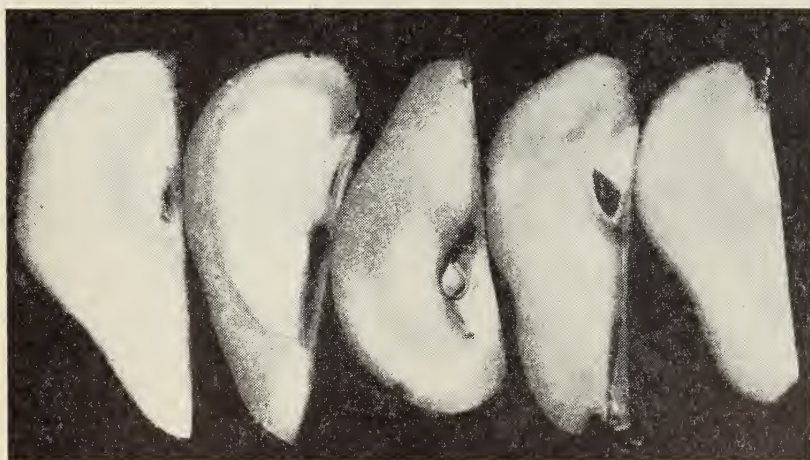


Fig. 4.—Appearance of sections of Bartlett pear halves after blanching in steam for various periods of time. Blanching times were, from left to right, 0, 4, 8, 12, and 16 minutes. Underblanched areas appear dull and chalky and are firmer than the blanched areas. (From *Food Industries*, vol. 15, no. 4, p. 59.)

test is not satisfactory, however, for clingstone peaches. Properly blanched fruit, after standing in the stack for some time, should be heated through, but not to the point where excessive bleeding or tissue breakdown occurs. Under-blanching fruit will retain firm areas, easily observed as described above. Bartlett pears in particular, when underblanched, tend to discolor because of oxidase activity. To avoid poor sulfur dioxide absorption and excessive bleeding in the sulfuring house, blanched fruit should be cooled sufficiently before sulfuring. Artificial cooling by means of fan blast is more efficient than cooling by natural draft, particularly with close-sided trays, or if cabinet-blanching, or mechanical car-loading pits are used.

Most of the excessive bleeding caused by overblanching takes place during subsequent sulfuring. Lovell and Muir peaches in particular have a strong tendency to bleed heavily if the fruit is overblanched. Sulfuring also causes the fruit to soften and become mushy, a condition accentuated by previous blanching. Phaff, Marsh, *et al.* (1945) found that bleeding can be eliminated by drying the fruit for 30 to 40 minutes before sulfuring, in a parallel-flow tunnel at a hot-end temperature of about 185° F. Fruit treated in this way should then be sulfured in the usual manner (Cruess, Friar, *et al.*, 1944) and dehydrated to completion in a countercurrent tunnel. It was found that soft-ripe apricots and most freestone peaches, with the exception of the Curry variety, tend to bleed unless predried as described above. Pears do not bleed, even when overblanched, because the skins are tough enough to prevent collapse of the fruit half.

An objection to blanching is the tendency of soft halves of apricots to flatten out and form slabs. This tendency is not so apparent in peaches and is absent in pears. Steam-blanching also tends to fix the green color (chlorophyll) so that, in order to produce an attractive dried product, the fresh fruit should be ripened evenly.

There are, however, several advantages in blanching freshly cut fruit halves. Blanched fruit is translucent and glossy, similar in appearance to the sun-dried product. Tilton apricots and peeled clingstone peaches assume a deep orange color very similar to that of the Santa Clara Valley sun-dried Blenheim or Royal apricot. Dehydrated unblanched fruit is dull and opaque. According to Crafts (1944 *a* and *b*) the air pockets in the tissues of unblanched fruit disperse light and give the dried product this dull, opaque appearance. (See fig. 5). Blanching rids the tissues of air and improves the appearance of the fruit. Three effects of blanching account for the displacement of intercellular air. First, the air is expanded by the heat, and most of it escapes from the cut surfaces through intercellular spaces. Second, the cells are killed by the heat and rendered permeable; in this way, the sap is allowed to escape. Third, the cell walls are softened, so that they bend and give under the compressional forces of surface tension.

Mrak, Phaff, *et al.* (1943) have observed that the retention of provitamin A (carotene) and ascorbic acid (vitamin C) is greater in blanched dehydrated fruit than in sun-dried. Other advantages of blanching are: (1) improved cleanliness of the product; (2) reduced drying time and higher sulfur dioxide retention; (3) superior retention of the fresh apricot flavor; and (4) reduction in time required for rehydrating and cooking. Dehydrated fruit is not

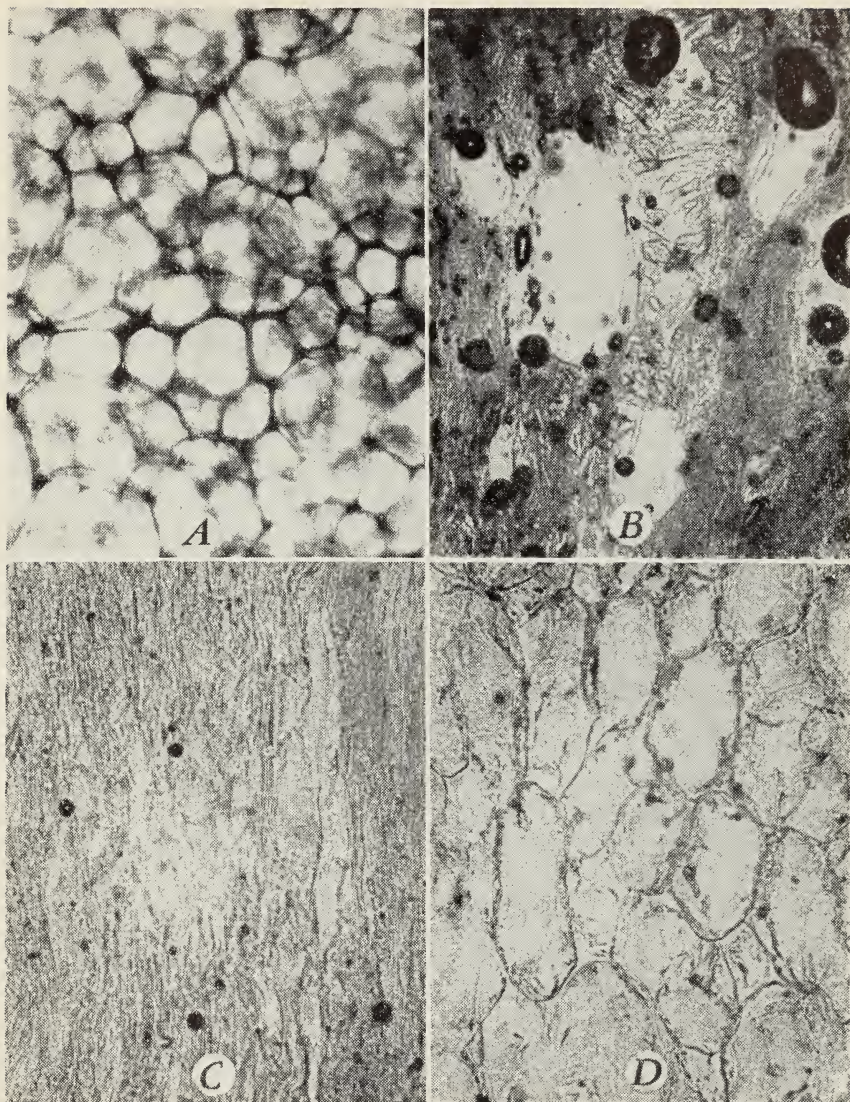


Fig. 5.—Royal apricot tissues, thin hand sections: *A*, Fresh tissue, showing thin-walled parenchyma cells and prominent air-filled intercellular space. *B*, Dried fruit, not blanched or sulfured. Large black dots are air bubbles. Transparent areas are cavities filled with air. (Section mounted in glycerin.) *C*, Blanched, sulfured, and dehydrated fruit. Note the almost complete absence of air. Very small black dots are carotene masses. (Section mounted in glycerin.) *D*, Same as *C*, but rehydrated. Small black dots are carotene masses. Note that blanching and dehydration have not destroyed cellular structure. (Photograph by A. S. Crafts.)

exposed to infestation and contamination while drying. Blanched apricots dehydrate in about two thirds of the time required for the unblanched fruit. With peaches and pears, the differences are greater. Large-scale cooking tests have shown that dehydrated blanched apricots require about 2 hours of soak-

ing and $\frac{1}{2}$ hour of cooking to become tender, whereas sun-dried fruits require much longer.

The storage qualities of the dehydrated blanched fruit are at least equal to those of the commercial sun-dried product, unless heat damage has occurred during dehydration.

Sulfuring.—Certain fruits are sulfured before dehydration to preserve their natural color and flavor, to prolong storage, to retard the loss of provitamin A and ascorbic acid, and to prevent microbial deterioration. Sulfuring is usually done after the fruits are cut or the skins are checked by lye-dipping to facilitate absorption of the sulfur dioxide.

The fruits sulfured before drying are: apricots, apples, peaches, pears, nectarines, Thompson Seedless grapes to be made into golden-bleached raisins, and a limited quantity of Kadota figs. Sour and light-colored varieties of sweet cherries should also be sulfured.

The best method of sulfuring is exposure of the cut fruit to fumes of burning sulfur in a closed chamber. In addition, apples are dipped in dilute bisulfite solution. Phaff (1945) has pointed out a number of factors which influence the absorption and retention of sulfur dioxide by the fruit. Time, temperature, and concentration of gas in the sulfuring house are factors of primary importance. Even when very high concentrations of sulfur dioxide are used, a minimum period for adequate sulfuring is required to obtain sufficient penetration of the gas into the flesh of the fruit.

Blanched apricots usually require from 2 to 3 hours, peaches 3 to 4, and pears 10 to 15 hours. Fisher, Mrak, and Long (1942) showed that cut fruits as well as whole fruits, such as grapes and figs, absorb less sulfur dioxide during sulfuring, but retain more after drying, when they are sulfured at a relatively high temperature, such as 100° to 120° F.

The concentration of sulfur dioxide in the average sulfuring house will range from $1\frac{1}{2}$ to 2 per cent by volume. Concentrations as high as 3 per cent by volume may be attained by burning sulfur in a tightly constructed house. Concentrations of about 2 per cent are advisable if satisfactory sulfuring is to be accomplished in a reasonable length of time. Long, Mrak, and Fisher (1940) have discussed fully the time and concentration factors related to the sulfuring of fruits.

The absorption of sulfur dioxide also varies greatly with the kind, variety, size, and maturity of the fruit. Apricots usually absorb more of the chemical than do peaches or pears. Immature fruit usually absorbs more sulfur dioxide than does mature fruit, but loses it much more rapidly during the process of drying.

Grapes and cherries dipped in an alkaline solution absorb sulfur dioxide more rapidly than does untreated fruit. During the process of drying, sulfur dioxide losses are more rapid when the skins are checked by lye-dipping. The use of certain salts, such as sodium citrate, will facilitate sulfur dioxide retention; these salts, however, have been used only experimentally. (See Mrak, Fisher, and Bornstein, 1942.)

Apples may be sulfured after they are peeled and cored, or after they are trimmed and sliced or quartered. Sulfuring fruit before cutting arrests discoloration and gives more uniform penetration than sulfuring sliced fruit

which is piled deeply on kiln floors. The disadvantage is that, after subsequent cutting, the freshly exposed surfaces are susceptible to oxidation and discoloration. Sulfuring after cutting is more uniform if the fruit is quartered, cubed, or sliced, and spread thinly on trays. To prevent discoloration before sulfuring, some driers, immediately after peeling, dip the fruit in a 2 per cent salt solution, although a 0.5 per cent solution of sodium bisulfite is preferable.

PREPARATION EQUIPMENT

Plant Layout.—The plant layout should be planned so that the fruit can move through the preparation line in a continuous flow, with a minimum amount of labor, power, and equipment. The preparation line may be operated during a 24-hour day or for any fraction of a day convenient to the operator. Operation periods of 8, 10, 12, or 16 hours are most commonly used for the preparation line. For economic reasons, if at all possible, the dehydrater must be operated continuously during the full season. As the preparation line customarily operates for a fraction of a day, storage tracks to hold extra cars of prepared fruit must be provided.

A plant design similar to that illustrated in figure 6 provides for a straight-line flow from the preparation line through the sulfuring house and tunnel to the finishing area; here the fruit is removed from trays to boxes. Storage tracks are located between the sulfuring houses and tunnels and near the finishing area. The tray washer is so located that every tray is washed before it is loaded. A plant of this type is suitable for grapes and prunes, but it would have to be modified considerably to be used for apricots, peaches, or pears. To accommodate these cut fruits it would need continuous cutting lines and a steam blancher (see fig. 7). Since the double-decking of trays in the blancher gives satisfactory results and doubles the output, a number of parallel cutting lines preferably should be built. These lines would then make a junction with the main feeding line into the blancher, and at this point double-decking could be done.

For apples, the plant layout must be different. In general, apples move from the receiving room through a peeling and coring machine, through a dipping trough, and on to a trimming table. From the trimming table the fruit is passed through a slicer into a sulfite bath equipped with a walker which conveys the fruit either onto trays or into a wheelbarrow for transfer to the kiln floor. Caldwell (1923) has described an apple-drying layout. He provides for a continuous sulfuring tunnel, which is still used in the Pacific Northwest. In this the whole apples, after being trimmed, cored, and dipped in a dilute bisulfite solution, are sulfured for about 45 minutes.

In planning a plant layout, sanitation should be given serious consideration. Cleaning equipment should be amply provided. Wash bowls, soap, and paper towels, conveniently placed in the cutting shed encourage the cutters to keep their hands clean. Drinking fountains are a great convenience. Sanitary toilets should be conveniently located. Employees should be instructed to wash their hands frequently and especially after use of the toilets. Sewage lines from toilets and lavatories should run to a septic tank, with the final disposal line outside the plant area or to a city sewer. Rotten and waste fruit should be removed daily and treated as previously described to prevent insect breeding.

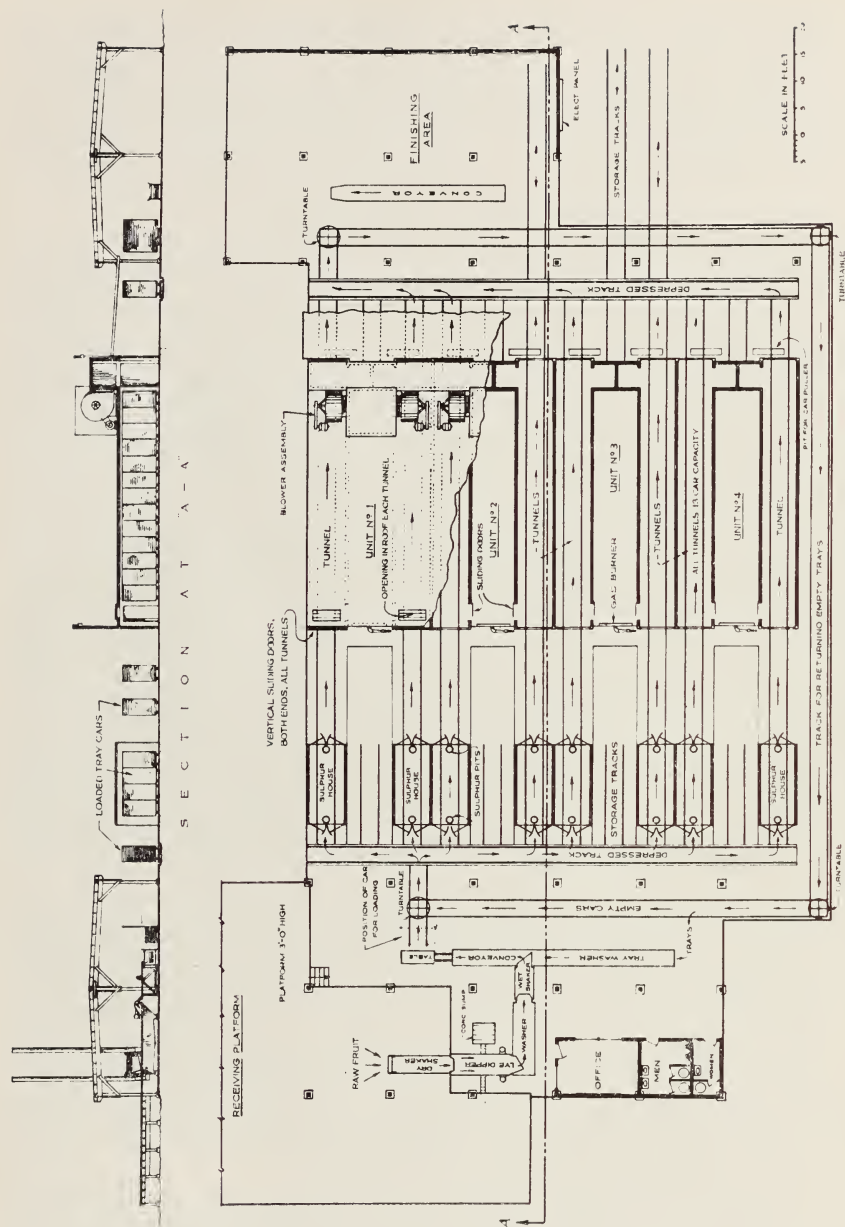


Fig. 6.—Grape dehydration plant, showing dipper, washer, sulfur houses, and dehydrator tunnels. (Courtesy of J. M. Montgomery and Company.)

Hosing and sweeping the cutting-shed floor should be part of the daily routine of cleaning. Dusty roads should be oiled or should be constructed on the side of the plant away from the prevailing winds, and no barnyards or corrals should be near the plant.

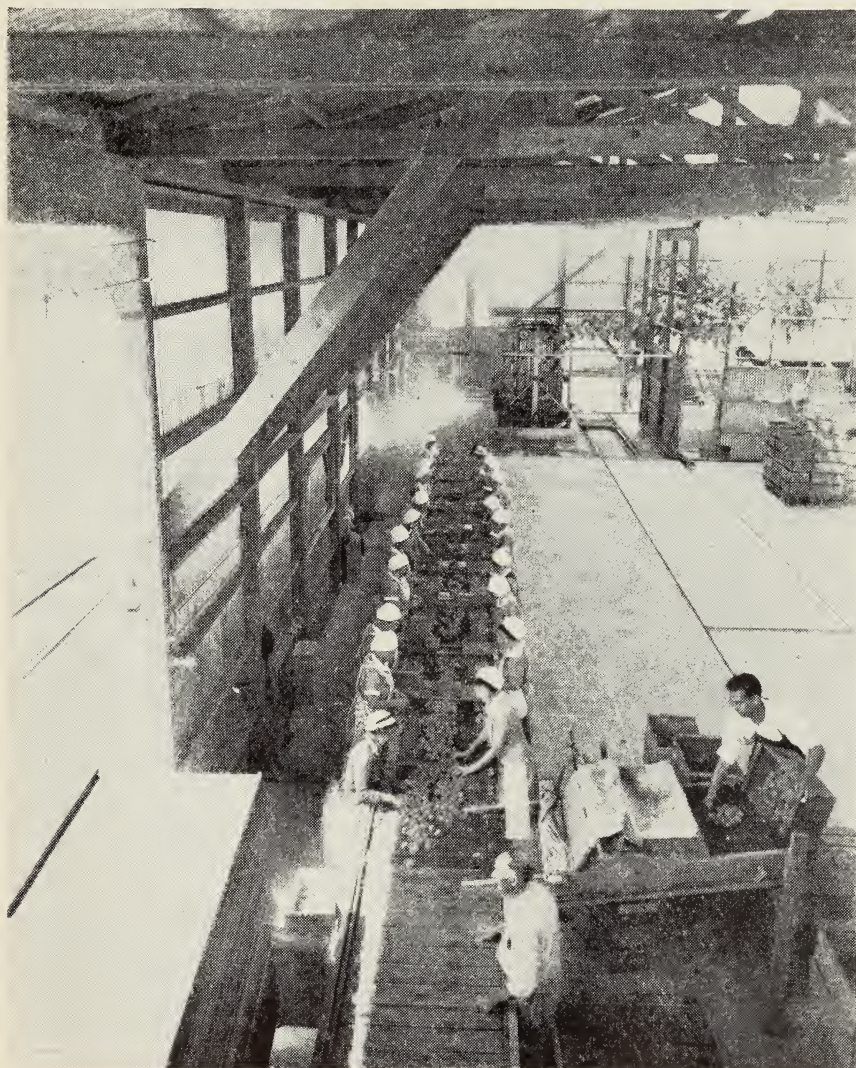


Fig. 7.—Cut-fruit preparation room showing continuous cutting table, blancher, and tray stacker. (Courtesy of John Leonard, Cupertino, Calif.)

Roads, cutting-shed floors, and paths along distribution tracks should be treated to settle dust, which otherwise may contaminate the fruit. Deliquescent salts, such as calcium chloride, spread on an earth surface absorb moisture from the atmosphere and keep the soil surface moist. The calcium chloride may be distributed at the rate of $\frac{1}{2}$ pound per square yard, and may be either

spread dry and raked into the surface, or dissolved in water and applied with a sprinkling can. In very arid localities, the atmosphere may not give up sufficient moisture to the chloride; here, treated areas may require one or two light sprinklings during the season. Being soluble in water, the chloride will be leached away by winter rains and will have to be replaced annually. On a cutting-shed floor it can be expected to last longer. Asphaltic oils of a heavy grade, with sufficient asphalt content to cement the soil surface may also be used. Lighter oils which do not consolidate the soil are objectionable, for coated particles that adhere to the fruit are difficult to remove by washing.

Fruit Boxes.—Wooden lug boxes about $15 \times 24 \times 9$ inches, to hold 40 pounds of fruit, are commonly used in transporting fruit to the cutting shed. The box should be made of lumber having a thickness of $\frac{1}{2}$ inch for the sides and bottom, and 1 inch for the ends; triangular corner posts should be 2×2 inches; and top cleats across the ends, $\frac{3}{4} \times 2$ inches. All material should be of pine, nailed on about 3-inch centers, around sides and bottom, with 6-penny, cement-coated box nails. The top cleats are essential to the protection of the fruit; they also give a space for ventilation when the boxes are stacked. In handling pears, boxes holding 44 or 45 pounds of fruit are used. The dimensions of these boxes are $14\frac{3}{4} \times 20 \times 10$ inches, including a $\frac{3}{4}$ -inch top cleat; or $14\frac{7}{8} \times 20 \times 10\frac{2}{3}$ inches, including a $2\frac{5}{8}$ -inch top cleat. Larger-sized boxes—holding 60 pounds of fruit—are not recommended for orchard use; they are difficult to handle and tend to bruise the fruit.

Boxes with the sides and bottom of exterior-grade Douglas fir plywood have been introduced; although higher in initial cost, they are durable and light in weight. Sheet-metal boxes have been used experimentally; their proponents claim for them the advantages of cleanliness, improved ventilation, less bruising because of improved shape, lower weight, and longer life. Of additional advantage is the fact that the boxes, when empty, require less storage and hauling space, since their design permits the stacking of one within the other.

Cutting Tables.—Plans for three types of cutting tables are obtainable from the Agricultural Extension Service, University of California, Berkeley, California. Continuous cutting tables are preferable; they eliminate much laborious handling of trays and facilitate the movement of freshly cut fruit directly from the cutting table into the blancher. Such a table is shown in figure 7. Where continuous cutting tables are used, the cutters may be paid either by the hour or by piecework. When the latter system is used, cutters should be shifted along the table periodically, or the last four cutters should be paid by the hour. If the fruit fails to fill the trays by the time it reaches the end of the table, a discontinuous system of operation may be used.

Blanachers.—Since apricots and freestone peaches are blanched for relatively short periods and may be easily overblanched, the use of a continuous blancher is advisable. Cabinet-blanching with present equipment does not appear feasible for them; there is too great a possibility of uneven heating throughout the tray stack, in the short blanching period that may safely be used. Cabinet blanachers may be used for pears and clingstone peaches, which require a long blanching period and show only a slight tendency to bleed.

Continuous vegetable blanachers, similar to those used for blanching trays of cabbage, are suitable for cut fruits. Because fruit must be blanched on trays,

care must be taken to attain smooth movement of trays through the blancher in order to avoid turning the fruit. Openings for steam jets should not be pointed toward the fruit, because of the danger of mechanical damage; they should slant downward, about 2 inches apart. To avoid steam currents which would overturn fruit, the openings should face each other in each successive steam pipe inside the blancher. Either a narrow blancher accepting trays in lengthwise position or better still, a wide blancher carrying trays in crosswise position may be used. The latter is more suitable for large-scale operations.

When some blanchers were found to form bottlenecks, as compared with the operation of other plant equipment, the expedient of using trays double-decked was tried; examination of the product indicated little difference in the results between top and bottom trays. The trays should be separated or so constructed that steam may flow freely to the fruit on the lower tray.

If the following factors are known, one can easily calculate the required length of a continuous blancher.

1. Maximum blanching time in minutes for a given fruit ($= t$).
2. Average tray load in pounds for a given fruit ($= L$).
3. Dimension in feet of a tray measured in the direction of travel through the blancher ($= W$).
4. Desired capacity in pounds of prepared fruit per hour ($= C$).

Assuming that double-decking of trays is used, the necessary blancher length should be computed by substituting the proper values for the letters indicated in the following formula:

$$\text{Blancher length} = \frac{C \times W \times t}{L \times 120}$$

The following table shows maximum blanching time and average tray load for a few fruits:

| Fruit | Maximum blanching time, minutes (t) | Average tray load, lbs. (L) |
|--------------------------|---|---------------------------------|
| Apricots | 3.5 | 35 |
| Clingstone peaches | 12 | 45 |
| Freestone peaches | 8 | 50 |
| Pears | 20 | 70 |

Example:

A plant manager wants to cut 6 tons of apricots per hour. The waste may be assumed to be 10 per cent. Amount of cut fruit per hour 10,800 pounds ($= C$). $t = 3.5$; $L = 35$; $W = 3$ for a blancher in which 3×6 foot trays go crosswise. With double stacking, the effective required blancher

$$\text{length} = \frac{C \times W \times t}{L \times 120} = \frac{10,800 \times 3 \times 3.5}{35 \times 120} = 27 \text{ ft.}$$

With single trays, the blancher length should be twice as long.

After the trays leave the blancher they must be stacked on cars. Since the lifting of loaded and hot trays is hard on the workmen, loading pits or a mechanical tray stacker similar to the one illustrated in figure 8, are recommended.

Boilers.—Oil- or gas-fired boilers are used to supply steam for blanching, and sometimes for heating washers, dippers, and peelers. Steam is also used for cleaning purposes. Because of the relatively short operating season, low initial cost is more important than high fuel efficiency. In many instances, reconditioned oil-field-type boilers have been installed. A permit to operate any boiler carrying over 15 pounds per square inch pressure, with the boiler subject to inspection, is required by the California Industrial Accident Commission. The purchaser of a used boiler should require that the boiler be in condition to pass inspection.

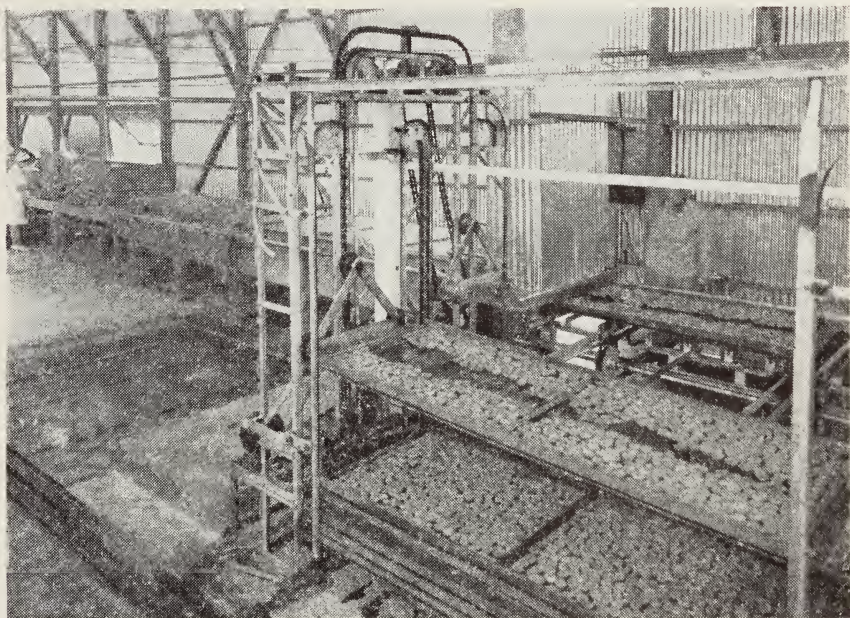


Fig. 8.—Mechanical tray stacker in operation. The loaded trays pass from the continuous cutting line at the extreme left, through the blancher onto the tray stacker, where they are lifted, carried over to the car being loaded, and then lowered onto the stack. (Courtesy of John Leonard, Cupertino, Calif.)

The custom of rating boilers in horsepower persists in the industry, although steam is seldom used for the generation of power in food-processing plants. The “builder’s rating” is based on a unit of 10 square feet of heating surface per rated boiler horsepower. The rate at which steam is produced in a boiler is often spoken of in terms of “developed boiler horsepower,” or DB hp. A developed boiler horsepower is equivalent to a heat absorption rate of 33,480 B.t.u. per hour from the furnace. This will convert per hour about 30 pounds of water into steam under dehydration-plant conditions.

Some modern types of boilers are so designed and built that their performance will exceed the builder’s rating. The oil-field- or locomotive-type boiler, however, cannot be operated much above its rating without a considerable drop in efficiency. The horizontal return tubular boiler and the stationary Scotch boiler, which are used in some plants, will develop about 50 per cent above

their rating. Some types of water-tube boilers, installed in large industrial plants, develop from 250 to 600 per cent of the builder's rating.

The size of boiler required for a blancher can be estimated roughly from the amount of fruit to be blanched, by use of the following formula:

$$\text{DB hp.} = \frac{\text{Pounds of fruit per hour} \times \text{temperature change in } ^\circ\text{F}}{\text{Blancher efficiency per cent} \times 334.8}$$

To use this formula, the blancher efficiency must be estimated. Continuous straight blanchers with adequate manifolds and end baffles will have efficiencies between 30 and 40 per cent. Thus, to blanch fruit at the rate of 1 ton per hour, heating the fruit from 70° to 190° F, at an efficiency of 30 per cent,

the developed boiler horsepower must be $\frac{2,000 \times (190 - 70)}{30 \times 334.8}$, or 24. Blanching

3 tons per hour, with a horizontal return tubular boiler which will develop

150 per cent of its rating, will then require a rating of $\frac{3 \times 24}{1.5}$, or 48 rated

horsepower. This is equivalent to 480 square feet of heating surface. If the boiler is to be used for other services, additional capacity must be provided.

The thermal efficiency of a cabinet blancher may range from 46 to 60 per cent, an indication that it requires less steam than a continuous blancher. The steam demand, however, is intermittent; consequently, the boiler must be at least as large as for a continuous blancher.

Fruit Washers.—A shop-built continuous washer has proved satisfactory for washing apricots. In the use of this washer, the fruit is carried on an endless belt between water sprays, over a sorting table, and weighed onto trays ready for delivery to the cutting shed.

Immersion washers are usually employed for grapes and prunes. In a washer more commonly used in Europe, the fruit moves through a trough with a perforated false bottom. Aeration causes the fruits to rub against one another, with subsequent removal of dirt particles. For prunes, it is advisable to include in the preparation line an air blower, trash remover, and strong water sprays to remove adhering leaves, stems, clods, dirt, and other foreign materials.

After pears are cut—but before the trays are stacked—it is advisable to pass them under a water spray to remove adhering dirt and evidences of insect infestation. A hose with nozzle may be used, but more positive results will be obtained by passing the trays slowly under a battery of fixed spray heads, arranged to wash both top and bottom. At times the washing has been carried out after the trays were stacked on the cars. This is an unwise procedure, since the foreign material removed from one tray is merely deposited on the first tray below. The area under the spraying equipment and dripping tray stack on the car should be smooth concrete with suitable drain. A continuous-cut pear washer is shown in figure 9.

Washers and Materials for Spray-Residue Removal.—Spray-residue removal has been discussed by Allen (1937), Essig and Hoskins (1944), and Haller, Smith, and Ryall (1935).

For the removal of spray residue, the fruit should be passed through a vat or a spray of acid at 70° F. When an excessive amount of wax has formed, or when oil sprays have fastened much lead arsenate on the fruit, the use of higher temperatures or an alkaline wash may be necessary. Most alkaline washes leave much of the lead and impair the keeping quality of the fruit, although they do remove arsenic efficiently. In California, pears are nearly always sprayed with lead arsenate and require thorough washing before drying. Apples are also sprayed with lead arsenate; they do not need the spray residue so thoroughly removed as do pears, however, since they are usually peeled and cored before drying. Washing the fruit in a 0.5 to 1.0 per cent

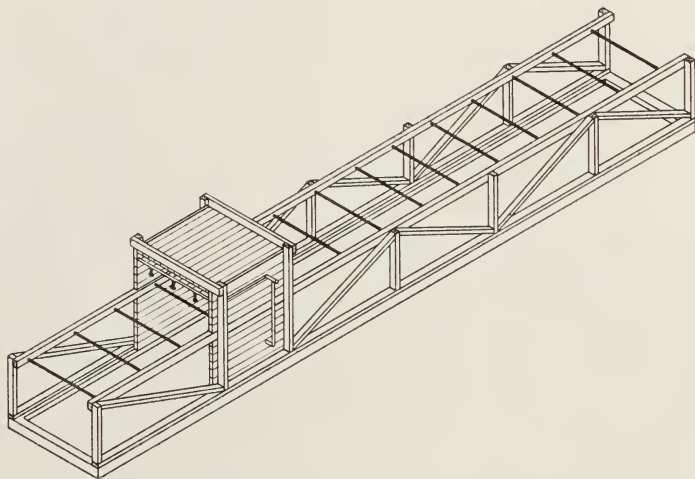
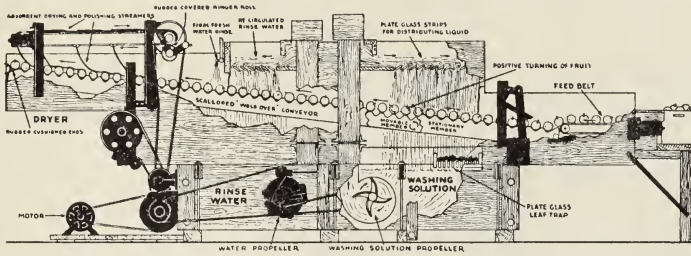


Fig. 9.—Cut pear washer. The loaded trays are placed on a roller conveyor and passed into a spray chamber where rows of spray heads, two from above and one from below, wash the fruit and the bottom of the tray. The conveyor and catch basin are extended to permit the trays to drain. (Plans through the courtesy of California Packing Corporation, San Francisco, Calif.; from California Agr. Exp. Sta. Cir. 350.)

solution of hydrochloric acid is a successful method. With simple immersion, a period as long as 3 minutes may be necessary; but with power-spray washing machines, 30 seconds may be sufficient. Removal of the calyx, or blossom end, and the stem of the pear after washing helps greatly in reducing the spray residue, which is found chiefly in these areas.

Two general types of washing machines are in common use. Simple dipping vats have not proved to be so effective as machines of larger capacity, such as conveyors and dipping vats, spray chambers and damp cloth or rubber wipers. They may be built from available designs, or they may be purchased prefabricated, as shown in figure 10. Somewhat simpler designs of washing equipment are being manufactured in local shops in fruit-producing areas of the state, the local designs usually being adequate. Responsible care in operation is required to maintain the solutions used at the concentrations and temperatures necessary for optimum results. In several instances smaller growers have found it advantageous to make use of large community fruit washers.

Peeling, Pitting, and Cutting Machines.—Where cling peaches are lyep-ealed, a standard peeler and pitter such as is used in canneries may be employed. Apples are always peeled and cored by machines, which may be either hand- or power-operated, and are sliced by power-driven machines. A pear-cutting machine has been evolved and tried in a few drying yards. Six stalls are provided where girls push the fruit against rotating spindles to remove



A

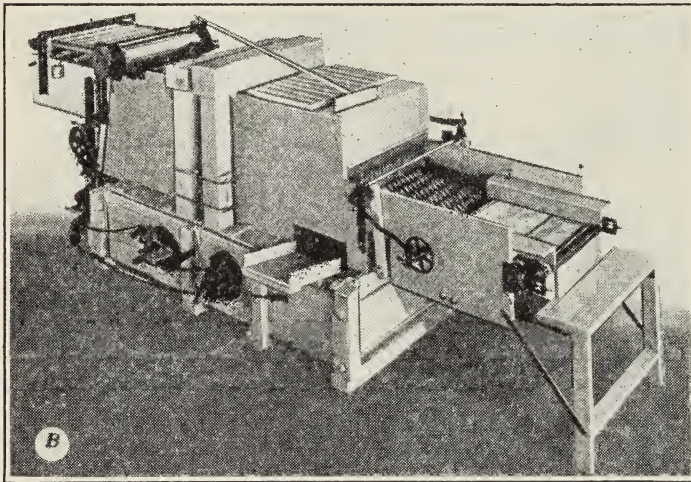


Fig. 10.—Fresh-fruit washer and drier for spray-residue removal: A, section sketch; B, photograph. (Courtesy of the Cutler Manufacturing Company, Portland, Ore.; from California Agr. Exp. Sta. Cir. 350.)

the calyx, then place it on a rope-belt conveyor, or specially constructed “cupped” conveyor leading over a rotary knife. Unless the fruit is properly placed on the belt it may be cut diagonally. Four women are required to tray the fruit as it leaves the knife; the entire crew handles about 60 boxes of fruit per hour.

Miscellaneous Small Equipment.—Sharp cutting knives and satisfactory equipment for sharpening them should be provided. A container for rotten and cull fruit should be placed conveniently for each cutter; its contents should be emptied frequently for removal to a dumping place remote from the drying yard. Pit boxes which clip to the side of the fruit box, or hang from the side of the cutting table, should be provided for stone fruits. Cutters

should be informed that whole fruit dumped on the tray bruises unnecessarily and tends to smear rotten particles over fruit and tray. Pits must be kept separate from rotten fruit. They should not be thrown into the fruit box; they make the boxes sticky, which, in turn, mars the appearance of the fruit. A wooden or concrete platform adjacent to the cutting shed should be provided for the drying of pits.

A satisfactory record for payment of the cutters consists in the use of a system of numbered cards and a foreman's punch to indicate the number of boxes cut each day.

Tray and Box Washers.—It is imperative that trays and fruit boxes be kept clean. Some fruit juice adheres to the wooden surfaces with each handling; this results in an accumulation of dirt and mold that may contaminate and injure the appearance of the dried product. Soaking the boxes or trays in a vat of clear water, or in a heated solution of trisodium phosphate, or in some other cleansing material, then scrubbing them thoroughly with a stiff bristle or wire brush, and rinsing in clear water will cleanse satisfactorily. Or a strong lye solution may be applied by a power orchard sprayer. It should likewise be vigorously brushed with a wire brush, and then rinsed off. The strength of the cleansing solution will be determined by the condition of the trays, and whether or not brushes are used. These alkaline cleansing agents must be used with care, because they can cause serious skin burns. A continuous tray washing machine installed in the line is desirable. One such washer has a rotary fiber brush under which the trays move continuously. Another type has reciprocating-motion fiber brushes, with interrupted movement of the trays to permit brush operation from the side. The second type has the advantage of working more closely into the corners than the rotary brush, and of rubbing with the grain of the wood in the tray bottoms. If heated water is used, 2 operators can clean 3 to 5 trays a minute at a total cost of about $\frac{7}{8}$ cents a tray.

To reduce mold growth on trays during off-season storage, they should be thoroughly washed and dried, then stored under a shed where ventilation is good.

Skin-checking Equipment.—Grapes and prunes are dipped before dehydration. The simplest dipper consists of a semicylindrical dump basket, with a perforated sheet-metal or wire-screen bottom, hinged to one side of the lye tank. The fruit is poured from the boxes into the heated lye solution while the basket is submerged. After the desired period of immersion, the basket is raised by a hand-operated lever; the fruit is then discharged upon a shaker or a chute, which is provided with water sprays and leads to the trays.

For large-scale operations, a power-driven rotary or a conveyor-type dipper is more suitable. The rotary dipper used for prunes consists of a perforated metal cylinder mounted on a horizontal axis and containing a helical baffle to maintain positive discharge. The lower third of the cylinder is submerged in the lye bath. The prunes are introduced continuously at one side and discharged at the other. A variable control on the speed of rotation governs the time of immersion. The conveyor-type dipper has either baskets suspended from chains or a metal belt with cross vanes to carry the fruit. This type of dipper enters at one end of an elongated lye tank and emerges at the

other. The conveyor discharges the fruit on a shaker or a chute leading to the trays, where water sprays remove excess lye.

The lye tanks are usually built of black iron instead of galvanized iron, because zinc galvanizing dissolves in lye. The vats are generally heated by oil burners, but gas, wood, coal, or steam may be used. In order to maintain the temperature of the solution at or near the boiling point, a relatively large heating surface and ample heat are necessary. The tanks usually hold 100 to 200 gallons or more; this relatively large volume of solution tends to maintain a more uniform temperature.

The use of a trash screen, before the fruit enters the lye bath, is a material aid in maintaining a clean dipping solution. It is not usually provided in hand-operated basket dippers, but is commonly installed on power dippers. All types of dippers should have a screen between the lye tank and the tray, where additional debris and the film of hot lye may be removed with sprays of cold water. This screen is usually mounted as a shaker.

Pricker or needle boards for prunes are sometimes used between the lye bath and the tray; they are not very satisfactory, however, because they are difficult to clean and keep in good order. Furthermore, they appear to be of little value except for use with the thin-skinned varieties of prunes, such as the Imperial, the dipping of which requires little or no lye.

Prune dippers are often provided with grading screens, which segregate the large, plump prunes from the small or shrunken ones and permit the trays for the two grades to be handled separately. This process accomplishes more uniform drying.

Commercial caustic soda, or sodium hydroxide in flake form, is commonly used in the preparation of dipping solutions. It quickly absorbs moisture and carbon dioxide from the air; therefore, it should be kept in tightly closed metal containers. The amount in the vat, or concentration of the solution, varies with the character of the fruit and with other conditions. Usually it is adjusted to give a uniform checking of the fruit skin to the degree found best by experience. Overchecking, with consequent loss by excessive bleeding, must be avoided. The concentrations of lye commonly used range from $\frac{1}{2}$ to 1 per cent at a temperature of about 200° F. Some large operators maintain the lye concentration by allowing a concentrated solution of lye to drip very slowly into the dipping tank.

Small producers will find it advisable to purchase lye in 1-pound containers; larger producers will find purchases in either flake or liquid forms in drums more economical.

Sulfuring Houses and Burners.—In large driers, as a precaution against fire, the practice is considered advisable to construct the sulfuring houses as two or more separate structures, rather than as one continuous building. They are of diverse design and construction. In a survey, made by Long, Mrak, and Fisher (1940), very few houses were found adequate. The requirements for these houses are economy in construction and durability under severe usage. Their design should promote rapid, uniform sulfuring, and should make them permanently tight against air infiltration and gas leakage. The compartment may be of a size to hold 1 or more stacks of trays, but should not contain excess space beyond the 6-inch clearances for convection circulation of air about the

stack and the open ends of the trays. The most positive convection distribution of sulfur dioxide gas is secured by making the compartment longer than the tray stack, so that the burner may be placed on the floor between the car and the door without fire hazard.

For sulfur burners, clean metal pans are recommended; earth pits into which sulfur is sometimes dumped for burning not only are grossly wasteful of sulfur, but are also a major factor in the production of poor-quality fruit. A tin pan 10 inches in diameter and about 3 inches deep makes a very satisfactory burner for a single-car house. Concrete hearths, of an area equivalent to that of the pan burners, and shallow enough to permit easy cleaning, are satisfactory. Insulated, regenerative, or forced-draft burners may be advisable for burning the poorer grades of sulfur, or sulfurs which do not ignite well because of contamination.

Care must be taken to prevent the burning rate from becoming so rapid that some sulfur is carried through the flame and sublimed on the fruit. It is preferable to use pan burners and sulfur that burns readily. An operator can test the extent to which a particular lot of sulfur will burn, by igniting a weighed quantity of the sulfur in a weighed 10-inch pan in an empty, but closed, sulfuring house. After the sulfur has ceased to burn, the pan should be removed and weighed with any remaining slag. The percentage of sulfur burned can then be calculated.

Where the compartment is short and the burner pan must be set in a pit under the end of the tray stack, a metal baffle sheet may be fastened under the end of the car for fire protection. Loose baffles laid over the pit are likely to reduce the opening materially and to restrict the burning rate, with resultant lower sulfur dioxide gas concentrations.

In a house of sufficiently tight construction to prevent drafts, vents will be required to provide air for the fire—an inlet of not more than 1×2 inches beside each track at the base of the door, and outlet holes of 1-inch diameter located at the top center of both the rear wall and the door. When a 10-inch diameter pan is used as a burner, these outlet vents provide about 1 square inch of area to 50 square inches of burner surface. This ratio must be maintained and the vent area modified, if the burning area is changed by varying the pan size or by using more pans—which may be necessary in a large house.

A good grade of refined sulfur is recommended because it is more economical and less troublesome than cheaper grades. The sulfur should burn completely, leaving not more than 1 or 2 ounces of residue from the standard 4- or 5-pound charge per car containing about 1,000 pounds of cut fruit. If an appreciable amount of slag remains, the cause may be surmised from its color; a clean yellow color indicates an insufficient air supply, whereas a black residue of carbonaceous appearance indicates a poor sulfur and one probably contaminated by oil or other organic material. Proper handling and storage of the sulfur supply is essential; it must be kept dry and must not be permitted to come in contact with oily surfaces or vapors. It should not be stored in garages, or near oil tanks. (See Bisson, Allinger, and Young, 1942).

Maintenance of the sulfuring house is a most important phase of plant management. To attempt to remodel old houses is poor economy, unless the framework is in good condition. If the structure is on mud sills it should be raised,

and a continuous concrete slab for floor and foundation poured. This base imparts a rigidity to the structure which helps keep it tight, and also holds the track firmly in position. Top-heavy, vertically sliding doors and swinging counterbalances for top-hinged doors cause warping and should be replaced by closely fitted and weatherstripped side-hung doors. All cracks and structural joints of the interior walls and ceiling, particularly those at the sill and plate, should be calked with asphalt mastic, with two coats of asphalt paint applied in a continuous film to seal the structure. All visible leaks other than vents must be closed. If the interior cannot be sealed readily, it should be lined with plywood and sealed at all joints with mastic or asphalt-impregnated felt with sealed edges. For a more extensive discussion of the principles and practices of sulfuring, the reader is referred to another publication of this station by Long, Mrak, and Fisher (1940).

As previously indicated, apples may be sulfured in a continuous sulfuring box or by immersion in a bisulfite solution for a short period of time, either alone or as a preliminary step to sulfuring with burning sulfur. The immersion equipment usually consists of a square wood tank with a walker, which moves the apples through the solution in about 2 minutes. The speed of the walker, however, should be adjustable. Iron should be avoided in sulfiting equipment.

Sulfur dioxide (SO_2), or sodium bisulfite (NaHSO_3) solutions may be used. Sodium bisulfite is most widely employed, however. It is economical to use, easy to handle, and has given very satisfactory results. The use of sulfur dioxide solutions has been limited by the difficulties of controlling concentration and the unpleasant environment for workers created by escaping gas.

PRINCIPLES RELATING TO DEHYDRATION

The principles underlying dehydration may be considered best with respect to the design and efficient operation of the dehydrator. The principles of dehydration have been discussed by Walker, Lewis, *et al.* (1937), Van Arsdel (1942), Cruess and Mackinney (1943), Eidt (1938), and Marshall (1942-43). Pierce (1942) and the Heating, Ventilating Air Conditioning Guide (American Society of Heating & Ventilating Engineers, 1945) contain valuable production supervision, engineering, and operation data.

The term *dehydration* as used in this bulletin may be defined as the removal of water from a product under controlled conditions of air flow, temperature, and humidity. Although drying *in vacuo* is being used for certain products, air is the common medium used in drying fresh fruits.

Process of Evaporation.—Water escapes from exposed wet surfaces by evaporation. The evaporation reduces the amount of water at the surface and increases the concentration of vapor in the adjacent space. Evaporation is a process which absorbs heat energy; consequently, a certain amount of heat energy known as the latent heat of evaporation must be supplied. This heat energy is immediately secured from the material composing the surface, and its loss lowers the temperature of the surface. Any reduction in fruit temperature enables heat energy to flow from the adjacent air by convection, from other directly visible surfaces by radiation, and from still other surfaces in direct contact through conduction. In a conventional dehydrator heat energy is supplied mostly by convection from rapidly moving heated air.

The rate at which evaporation proceeds depends upon the difference between the concentration of vapor at the wet surface and in the adjacent space, and also upon the resistance offered to the passage of the vapor through a relatively stagnant layer of air (air-vapor mixture) next to the surface.

The vapor concentration at the wet surface depends upon the nature and the moisture content of the material, and upon its temperature. For most rapid evaporation, the surface must be kept at as high a temperature as can be main-

TABLE 6
RELATION BETWEEN MOISTURE CONTENT EXPRESSED AS T (PARTS OF
WATER PER PART OF BONE-DRY MATTER) AND AS
PER CENT ON THE WET BASIS

| Per cent moisture | T | Per cent moisture | T | Per cent moisture | T | Per cent moisture | T |
|-------------------|------|-------------------|------|-------------------|------|-------------------|-------|
| 90.0 | 9.00 | 84.8 | 5.58 | 71.0 | 2.45 | 25.0 | 0.333 |
| 89.8 | 8.80 | 84.6 | 5.49 | 70.0 | 2.33 | 24.0 | .316 |
| 89.6 | 8.62 | 84.4 | 5.41 | 68.0 | 2.12 | 23.0 | .300 |
| 89.4 | 8.43 | 84.2 | 5.33 | 66.0 | 1.94 | 22.0 | .282 |
| 89.2 | 8.26 | 84.0 | 5.25 | 64.0 | 1.78 | 21.0 | .266 |
| 89.0 | 8.09 | 83.5 | 5.06 | 62.0 | 1.63 | 20.0 | .250 |
| 88.8 | 7.93 | 83.0 | 4.88 | 60.0 | 1.50 | 19.0 | .234 |
| 88.6 | 7.77 | 82.5 | 4.71 | 58.0 | 1.38 | 18.0 | .220 |
| 88.4 | 7.62 | 82.0 | 4.56 | 56.0 | 1.27 | 17.0 | .205 |
| 88.2 | 7.47 | 81.5 | 4.41 | 54.0 | 1.17 | 16.0 | .190 |
| 88.0 | 7.33 | 81.0 | 4.26 | 52.0 | 1.08 | 15.0 | .177 |
| 87.8 | 7.20 | 80.5 | 4.13 | 50.0 | 1.00 | 14.0 | .163 |
| 87.6 | 7.06 | 80.0 | 4.00 | 48.0 | 0.92 | 13.0 | .150 |
| 87.4 | 6.94 | 79.5 | 3.88 | 46.0 | 0.85 | 12.0 | .136 |
| 87.2 | 6.81 | 79.0 | 3.76 | 44.0 | 0.79 | 11.0 | .124 |
| 87.0 | 6.69 | 78.5 | 3.65 | 42.0 | 0.73 | 10.0 | .111 |
| 86.8 | 6.58 | 78.0 | 3.55 | 40.0 | 0.67 | 9.0 | .099 |
| 86.6 | 6.46 | 77.5 | 3.44 | 38.0 | 0.61 | 8.0 | .087 |
| 86.4 | 6.35 | 77.0 | 3.35 | 36.0 | 0.56 | 7.0 | .075 |
| 86.2 | 6.25 | 76.5 | 3.26 | 34.0 | 0.52 | 6.0 | .064 |
| 86.0 | 6.14 | 76.0 | 3.17 | 32.0 | 0.47 | 5.0 | .053 |
| 85.8 | 6.04 | 75.5 | 3.08 | 30.0 | 0.43 | 4.0 | .042 |
| 85.6 | 5.94 | 75.0 | 3.00 | 29.0 | 0.41 | 3.0 | .031 |
| 85.4 | 5.85 | 74.0 | 2.85 | 28.0 | 0.39 | 2.0 | .020 |
| 85.2 | 5.76 | 73.0 | 2.70 | 27.0 | 0.37 | 1.0 | .010 |
| 85.0 | 5.67 | 72.0 | 2.57 | 26.0 | 0.35 | 0.0 | 0.000 |

tained without damage to the material. The vapor concentration at the surface decreases as the moisture content is reduced; therefore, the evaporation rate diminishes as the material becomes drier.

The vapor resulting from evaporation must be dispersed as rapidly as it forms, in order to prevent the concentration in the adjacent space from rising and interfering with evaporation. Vapor is removed by permitting it to escape by natural convection, by sweeping it away with an air stream of lower humidity, or by operating in a vacuum chamber. Most dehydrators employ a stream of air moved at a rapid rate through the tunnels or cabinets by a fan.

The resistance to the escape of vapor, offered by the stagnant air layer at the fruit surface, depends upon the thickness of the layer, which is influenced by the turbulence and the velocity of the air stream. For rapid drying, the air velocity should be as high as is consistent with economy in fan power.

Air then performs two functions in the conventional dehydrator: it carries

away the vapor which is formed; and it supplies to the material being dried the heat energy which will be absorbed in evaporation. The air temperature should be high enough to keep the material at the maximum temperature which it can sustain without damage. A higher air temperature is permissible when the material is wet, not only because it is then less sensitive to heat, but also because it is cooled by rapid evaporation. The air-volume rate (cubic feet per minute) must be great enough to carry away the vapor without causing too high a moisture content in the exhaust air. The air velocity must be reasonably high in order to reduce the resistance to escape of vapor from the evaporating surface.

These generalizations can be applied effectively in dehydrater design and operation when physical properties of air-vapor mixtures, characteristics of the material to be dried, and principles of performance of fans, furnaces, and different types of dehydraters are known.

Moisture in Fruit.—The moisture content of a substance is usually expressed by the analyst in percentage by weight on the wet basis, or, in other words, in grams of water per hundred grams of sample. This method of expression might give an incorrect impression if it were to be used in describing the rate of drying, since both the moisture content and the basis on which it is figured are variable. If, however, the moisture is expressed as *moisture ratio*, part of water per part of bone-dry matter (water-free solids), a correct representation of the drying rate can be given, since the amount of dry matter remains constant, whereas the moisture evaporates.

The relation between the moisture content M , percentage on the wet basis, and the moisture ratio T , the pounds of water per pound of dry matter is

$$T = \frac{M}{100 - M}. \text{ Values of moisture ratio corresponding to given values of mois-}$$

ture content are given in table 6. For example, if the moisture content of fresh prunes is reported by the analyst to be 70 per cent, the moisture ratio is

$$\frac{70}{100 - 70}, \text{ or } 2.33 \text{ pounds of water per pound of dry matter. In this case, } 3.33,$$

(that is, $2.33 + 1$), pounds of fresh prunes contain 2.33 pounds of water and 1 pound of dry matter. If these prunes were dehydrated to a moisture content

$$\text{of 16.7 per cent, the final moisture ratio would be } \frac{16.7}{100 - 16.7}, \text{ or } 0.20 \text{ pounds of}$$

water per pound of dry matter. The amount of water evaporated in the examples given would be $2.33 - 0.20$, or 2.13 pounds of water per pound of dry matter. In a typical drying curve, figure 13, page 44, it can be seen that the drying rate, which is represented correctly by the steepness of the moisture-ratio curve, is quite different from that shown by the slope of the moisture-content curve, both plotted against time.

The drying ratio—the pounds of fresh material required to yield a pound of dried fruit—can be obtained either from the initial and final total solid contents S_1 and S_2 , or the moisture ratios T_1 and T_2 , thus

$$\text{drying ratio} = \frac{S_2}{S_1} = \frac{100 - M_2}{100 - M_1} = \frac{T_1 + 1}{T_2 + 1}.$$

For the initial and final moisture contents given above, the drying ratio is $\frac{100 - 16.7}{100 - 70}$, which is 2.78. Or it could be found as $\frac{2.33 + 1}{0.20 + 1}$, which is also 2.78.

The pounds of water which must be evaporated from 1 pound of fresh material to yield a product of the desired moisture content may be calculated as follows:

$$\text{Pounds of water evaporated per pound of fresh material} = \frac{M_1 - M_2}{100 - M_2} = \frac{T_1 - T_2}{T_1 + 1}.$$

The pounds of water which have been evaporated from the amount of fresh material needed to obtain 1 pound of dried product of the desired moisture content can be computed in the following way:

Pounds of water evaporated to

$$\text{produce 1 pound of dried product} = \frac{M_1 - M_2}{100 - M_1} = \frac{T_1 - T_2}{T_2 + 1}.$$

The moisture content and moisture ratio of the edible portions of certain fresh fruits that are commonly dried or dehydrated are as follows:

| Fruit | Range of moisture content (M) per cent of water | Range of moisture ratios (T) |
|----------------|---|----------------------------------|
| Apples | 82 to 86 | 4.56 to 6.14 |
| Apricots | 83 to 86 | 4.88 to 6.14 |
| Grapes | 80 to 83 | 4.00 to 4.88 |
| Peaches | 83 to 89 | 4.88 to 8.09 |
| Pears | 82 to 85 | 4.56 to 5.67 |
| Prunes | 70 to 80 | 2.33 to 4.00 |

The moisture ratio gives a better indication of the amount of moisture to be removed than does the moisture content in percentage on the wet basis.

Properties of Air-Vapor Mixtures.—The operator of a dehydrater must realize that there is a maximum limit to the absolute humidity, vapor density, or concentration of vapor, expressed as pounds of vapor per cubic foot, that can exist at any given temperature, as shown in figure 11, A. At the maximum concentration of vapor, the space in which the vapor occurs is said to be saturated—that is, if any more vapor were introduced, condensation would proceed until only the original amount remained.

The dehydrater must be controlled so that saturation will not be approached at any point lest the drying rate be too slow, and spoilage by microorganisms occur in unsulfured products. In the early stages of dehydration of sulfured fruits, excessive losses in sulfur dioxide occur if humidities are high and drying is prolonged, for, although the air may be saturated with moisture, it is far from being saturated with sulfur dioxide.

The term *relative humidity* is used to designate the degree of approach to saturation with water vapor at any temperature. Relative humidity is defined as the ratio of the concentration of vapor, for some given condition, to the concentration for saturation at the same temperature. Curves representing vapor concentrations for several relative humidities are also shown in figure 11, A.

In certain dehydrater calculations, confusion might arise in dealing with the pounds of water vapor per cubic foot, because the vapor is mixed with the air, which changes in density as it passes through the dehydrater. It is then desirable to use the *humidity* (pounds of water vapor per pound of air), which avoids this difficulty, because the weight of the air (weight of air free of water vapor) remains constant as it passes through the system, unless leaks occur. The relation between humidity and temperature is shown in figure 11, *B*, for several relative humidities.

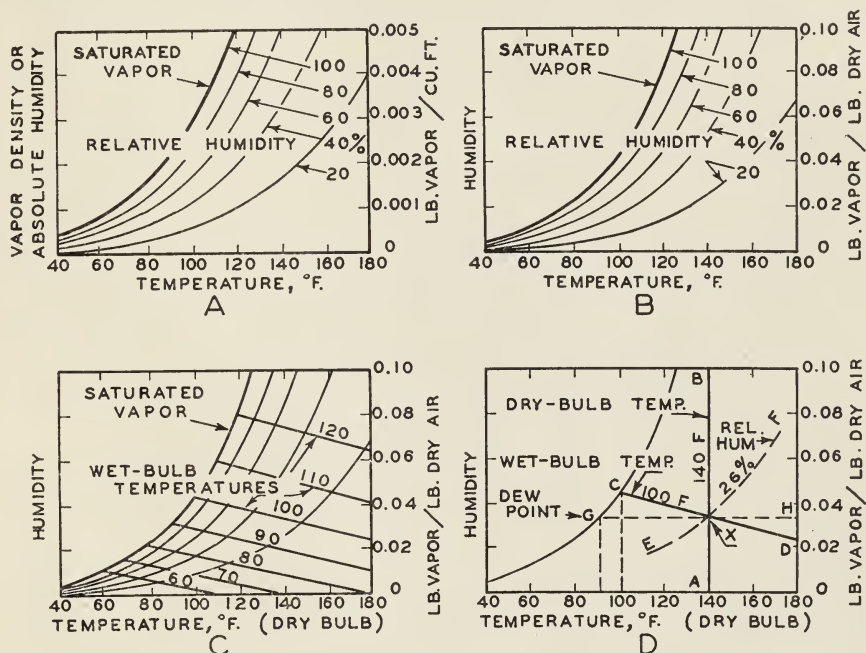


Fig. 11.—Temperature charts: *A*, Relation between vapor density, or absolute humidity, and temperature, at several relative humidities; *B*, relation between temperature and humidity (pounds of vapor per pound of dry air) at several relative humidities; *C*, relation shown in *B*, with wet-bulb temperature lines added; *D*, illustration of relations shown by psychrometric chart.

Measuring Air Conditions.—In order to adjust dehydrater controls for best operation, the operator must be able to determine the conditions of the air entering and leaving each unit. This can be done readily by means of a psychrometer, or wet-and-dry-bulb hygrometer. The instrument consists of a pair of thermometers, one of which has its bulb covered with a porous wick supplied with distilled water. An air velocity of about 600 feet per minute across the wick is desirable. For measurement in quiet or slowly moving air, hand instruments are available which permit whirling of the thermometers to secure the desired speed.

Various combinations of dry- and wet-bulb thermometers are available for permanent stationary mounting. The dehydrater should be equipped with such instruments; they should be properly placed at the air-exit end of the tunnel, conveniently located behind small glass windows in the tunnel walls.

To secure a correct reading, it is extremely important that air at high velocity should pass over the wet-bulb thermometer. Only distilled or rain water should be used to fill the reservoir that moistens the wick. Because tap and well waters contain salts, which accumulate on the wick and interfere with the evaporation of water, the wet-bulb thermometer will give too high a reading, and this will result in serious error. An error often occurs in tunnels drying sulfured cut fruit, because some of the sulfur dioxide is transformed into sulfuric acid; this deposits on the wick, digests the fabric, and causes erroneous readings. When sulfured fruits are being dehydrated, the wicks should be renewed every 2 weeks.

When the air stream passes over the bulbs, the bare thermometer indicates merely the temperature of the air (called the dry-bulb temperature, to distinguish it from the temperature of the wet-wick-covered thermometer). The air passing over the wet-bulb thermometer is usually not saturated with vapor; consequently, evaporation can occur and cool the wick. As the wick gets colder, the evaporation rate declines, while heat flowing in from the adjacent air tends to maintain the wick temperature. A balance is soon reached, at which point the heat flow to the wick is just rapid enough to supply the heat absorbed in evaporation; the temperature of the wet bulb remains constant as long as the wick is wet. In saturated air, no evaporation can occur to cool the bulb, whereas in moisture-free air maximum cooling results. From the dry- and wet-bulb readings, the relative humidity and other properties of the air can be found by reference to appropriate tables or charts.

The Psychrometric Chart.—Charts which show only the relative humidity corresponding to given values of dry- and wet-bulb temperatures are quite simple; but a much clearer understanding of the processes which occur in dehydration can be gained from psychrometric charts which show additional properties of air-vapor mixtures, drawn so that the changes which occur in the dehydrator can readily be depicted. A chart which shows the maximum amounts of moisture that can be removed without approaching too close to saturation is especially useful.

In the psychrometric chart which seems best adapted to use by dehydrator operators, the air temperatures (dry-bulb temperatures) are represented on the horizontal scale, and the humidity (pounds of vapor per pound of dry air) on the vertical scale. On these coördinates, curves are drawn showing the relation between the temperature and the humidity for a series of relative humidities. Figure 11, *B* thus forms the skeleton of this type of chart,¹⁴ but it lacks the wet-bulb temperature lines, which are added in figure 11, *C*. It will be noted that at saturation, the wet-bulb temperature equals the dry-bulb temperature, for example, point *C*, in figure 11, *D*. For a low relative humidity, the wet bulb is much colder than the dry bulb, point *X* (for 140° F dry bulb and 100° wet bulb 26 per cent relative humidity).

¹⁴ Those interested in a complete chart may purchase an enlarged copy of a chart by H. J. Garber, reproduced from the Chemical Engineering Catalog, by writing to the Book Department, Reinhold Publishing Corporation, 330 West 42 Street, New York, N. Y. Instead of relative humidity curves, Garber's chart shows per cent humidity curves. Per cent humidity is defined as the humidity for a given condition, divided by the humidity for saturation at the given temperature. It differs only a little from relative humidity, and a conversion chart is provided.

The use of the chart is illustrated in figure 11, *D* for a typical condition of a dry-bulb temperature of 140° F and a wet-bulb temperature of 100° . This air condition is found at point *X*, the intersection of line *AB*, which represents all conditions with a dry-bulb temperature of 140° , and line *CD*, which represents all conditions with a wet-bulb temperature of 100° . The point *X* is just above the curve *EF*, a 26 per cent relative-humidity curve.

The humidity for this condition is also illustrated in figure 11, *D*. All points on the horizontal line *GH* passing through *X* are at the same humidity. The numerical value is read from the right-hand scale at *H*, as 0.033 pounds of vapor per pound of air.

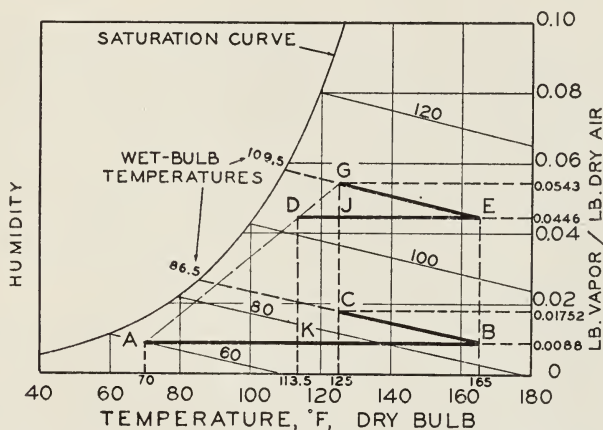


Fig. 12.—Use of psychrometric chart in dehydration problems.

The dew point of an air-vapor mixture is the temperature at which condensation would begin, if the mixture were cooled without change in composition. This is illustrated in figure 11, *D* at the point *G*, which is on the saturation curve at a temperature of 92° F. During much of the fruit-dehydration season in California the humidity ranges between 0.008 and 0.010, corresponding to dew points from 51° to 57° .

The psychrometric chart is particularly useful because changes in air conditions which occur in the dehydrator are readily represented on it. The three principal changes are: (1) heating the air before it is delivered to the tunnel or cabinet; (2) passing the air across the fruit, where it picks up moisture and gives up heat; and (3) mixing exit air from the tunnel with fresh air when recirculation is used.

Heating of air without addition or removal of moisture is illustrated by line *AB* on figure 12. Air at 70° F dry-bulb and 60° wet-bulb temperatures, point *A* (humidity of 0.0088 pound of vapor per pound of dry air, relative humidity 55 per cent, dew point 54°) is heated to 165° , point *B*. At *B* the humidity is the same as at *A*. The wet-bulb temperature is found from the chart to be 86.5° , and the relative humidity 4 per cent.

The changes which occur in air as it passes through the trays of fruit can be found readily from the psychrometric chart. The vapor from evaporation mixes with the air and raises the humidity. The air must supply the latent heat of evaporation, and also the heat for warming the fruit, trays, and trucks

and the heat losses through the walls, ceiling, and floor. The evaporation of a pound of moisture at a typical fruit temperature of 130° F during evaporation requires 1,020 B.t.u. Warming the trays, trucks, and dry matter of the fruit to the temperature at which they leave the dehydrater, and warming the moisture which does evaporate to its evaporating temperature, require in addition only about 80 B.t.u. A pound of nearly dry air provides about 0.24 B.t.u. for each degree drop in temperature. Thus, a pound of air

can supply the heat energy for evaporating $\frac{0.24}{1020 + 80}$, or 0.000218 pound of moisture, for each degree drop in air temperature.

For an illustration on the chart, typical prune dehydrater temperatures will be chosen, namely, an air temperature of 165° F entering the tunnel, and 125° leaving the tunnel. With this temperature drop of 165°–125°, or 40 degrees, the humidity will rise by 40 times 0.000218 or 0.00872 pounds of vapor per pound of air. With the initial condition of point *B* (165° dry bulb, 0.0088 humidity, and 86.5° wet bulb) the final condition will be a dry-bulb temperature of 125° and a humidity of 0.0088 + 0.00872, or 0.01752. It is notable that when a point to represent this condition (point *C*) is placed on the chart, its wet-bulb temperature is found to be 86.5°.

The above example illustrates a very nearly exact general rule: *When air supplies the heat energy for evaporation, its exit wet-bulb temperature is the same as its entering wet-bulb temperature.* This is a very convenient, albeit fortuitous, circumstance which greatly simplifies dehydrater design and control. *Lines which represent wet-bulb temperatures on the psychrometric chart also represent the drop in temperature and simultaneous rise in humidity of air passing through the dehydrater.* It is thus possible, by following a wet-bulb line, to estimate the amount of vapor which can be absorbed by air passing through the dehydrater by the time its relative humidity has risen to a point where dehydration will be materially retarded. With fruits in a counter-current tunnel, for example, this point has been found to be a relative humidity of about 60 per cent.

Calculation of the efficient utilization of heat energy of the air in the tunnel can be illustrated by using the data from the preceding examples. Line *AB*, figure 12, represents heating the air from 70° to 165° F, while line *BC* represents the useful drop in temperature of the air which is supplying the energy for evaporation. The heat energy involved in each of these is proportional

to the temperature changes of the air. The tunnel efficiency is then $\frac{165-125}{165-70}$, or

42 per cent. In this illustration the efficiency was low because, although the air had to be heated from 70°, it was exhausted at 125°.

When a psychrometric chart is not available, a simple rule of thumb can be used to estimate the evaporation rate in a dehydrater. As shown above, a pound of air can pick up 0.000218 pound of vapor for each degree drop in temperature. In rough calculations, it is often more convenient to use the volume of the air, which can be more readily measured, than the weight. In the dehydrater, a pound of air occupies about 16 cubic feet. Each cubic foot can then

pick up $\frac{0.000218}{16}$, or 0.0000136 pound of moisture for each degree drop in

temperature. The evaporation rate is approximately equal to 0.0000136, multiplied by the air flow and the air temperature drop, or

evaporation rate, in pounds of vapor per minute = $0.0000136 \times \text{air flow} \times \text{tem-}$

perature drop, or = $\frac{\text{cubic ft. per minute} \times (\text{air temperature drop})}{80,000}$.

The value of 60,000, sometimes given as the constant in the above equation, is based upon measurement of the air volume at a temperature of 60° F, which is seldom applicable to fruit dehydration.

Recirculation.—The psychrometric chart is of great help in considering the recirculation of air in a dehydrater. With slow-drying fruits, such as prunes or grapes, air of the usual outside humidity will not reach a practical limit of its evaporative capacity in a single passage through the trays, unless the tunnel is unusually long or the velocity unduly low. In the example given on page 42 for operation without recirculation, fresh air was heated to 165° F and cooled by evaporation in the tunnel to a typical temperature of 125°, where it had a final relative humidity of only 20 per cent. The final relative humidity can be higher, up to 60 per cent, without materially lengthening the drying time of fruits. By opening the by-pass, or recirculation door, and, if necessary, partly closing the exhaust door, some of the humid air leaving the trays will pass into the heating chamber and the humidity will rise throughout the dehydrater. When part of the air is being recirculated, less fresh air has to be taken in and heated. The recirculated air itself will require less heating than the fresh air. Thus, a very substantial fuel saving may be realized.

Although to measure the volume of the fresh and recirculated air, or the temperature of the mixture, is usually inconvenient or impossible, the conditions can be readily determined from the psychrometric chart. For example, the same initial and final air temperatures, 165° and 125° F, will be taken as in the preceding example for operation without recirculation.

At the final air temperature of 125° F, with the relative humidity permitted to rise to 60 per cent, the final condition is represented by point *G*, figure 12, where the wet-bulb temperature is found to be 109.5° F and the humidity 0.0543 lb. of vapor per pound of air. Since, in passing over the fruit, the air conditions must have followed the wet-bulb line, the initial condition must have been at point *E* (109.5° wet bulb and 165° dry bulb), where the relative humidity is found to be 13 per cent, and the humidity 0.0446. The air given by point *E* is the mixture of fresh and recirculated air, which has been heated by the furnace. Before it was heated, its humidity must have been the same as at *E*, or 0.0446; its temperature before it was heated may be found from the chart. This can be done because the mixture has been formed from fresh air at *A*, and exit air at *G*.

The rule for mixtures of humid air is: The condition of mixture *D*, made up partly of air of condition *A*, and partly of air of condition *G*, must lie on the straight line from *A* to *G*. The quantities of each component are inversely proportional to the distances of the final condition *D* from the condition of

each component. Instead of distances DA and GD , the horizontal or vertical projections (KA and JD representing temperature or DK and GJ representing humidities) may be used.

Since the condition of the mixture lies on the line AG with a humidity of 0.0446, it is represented by the point D . The temperature of the mixture is found from the chart to be 113.5° F. Thus, in these examples, fresh air must be heated from 70° to 165° , or 95 degrees when recirculation is not used, while the mixture resulting from recirculating need be heated only from 113.5° to 165° , or 51.5 degrees. Neglecting the slight differences in heat capacity and

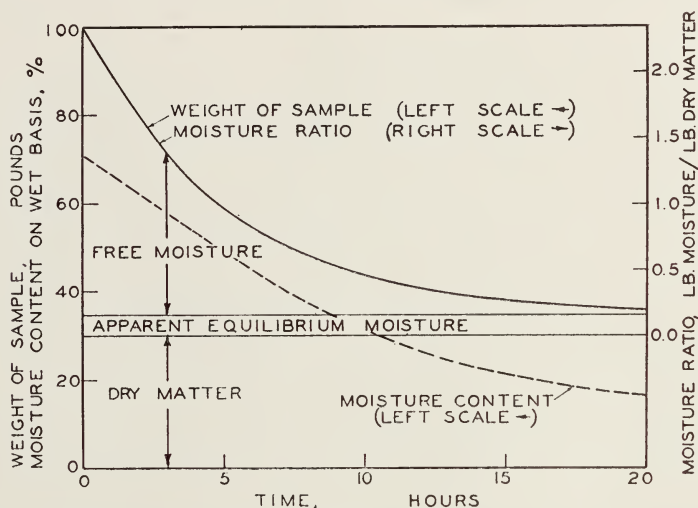


Fig. 13.—Change in weight of a sample of prunes during a laboratory dehydration test in a cabinet drier at constant temperature and humidity.

volume, the saving in heat can be estimated from the temperature changes. Recirculation saves heating from 70° to 113.5° , or 43.5 degrees. The fuel saving is 43.5 out of 95, or 46 per cent. The tunnel efficiency with recirculation is

$$\frac{165 - 125}{165 - 113.5} = 77.8 \text{ per cent.}$$

Drying Rates and Drying Times.—The time required for drying is determined by the amount of moisture to be removed and by the removal rate. In order that conditions favorable to rapid drying may be economically provided, the several factors which influence drying rates should be understood.

The drying rates of many commodities, including fruits, have been found to be very nearly proportional to the moisture ratio, that is, to the pounds of moisture per pound of dry matter. This relation between drying rate and moisture ratio is illustrated in figure 13, which shows the weight of a sample being dried in a cabinet where the air temperature and humidity are kept constant during the process. It is apparent that the drying rate is high when the moisture ratio is high, and decreases as the amount of water decreases. Even if the sample were kept in the cabinet for a prolonged length of time, the moisture ratio would not drop below a certain value, the *equilibrium*

moisture ratio. The equilibrium moisture ratio depends principally upon the relative humidity and is influenced to a smaller extent by the temperature. The moisture that is free to evaporate can be found by subtracting the equilibrium moisture ratio from the total moisture ratio. Fortunately, fruits are not dried to low moisture contents; as a consequence, drying can ordinarily be completed without providing air of extremely low relative humidity. The drying rates of fruits are almost exactly proportional to the free moisture ratios, except when moisture ratios below commercial practice are approached.

The drying rate also depends upon the fruit temperature, but, since this cannot be readily measured in commercial operation, it is more convenient to refer to the temperature of the air passing around the fruit. For prunes and raisins, drying rates have been found to be proportional to the fourth power of the Fahrenheit temperature of the adjacent air. The relative effect of temperature is as follows :

| Temperature, ° F | Relative drying rate |
|---------------------|-------------------------|
| 150 | 0.68 |
| 155 | 0.78 |
| 160 | 0.89 |
| 165 | 1.00 |
| 170 | 1.12 |

The influence of humidity upon the drying rate is different with materials of different nature. For commodities of such a nature that freely evaporating surfaces are maintained while most of the water is being evaporated (diced or julienne cut, sliced, and shredded vegetables) the rate is roughly proportional to the wet-bulb depression (dry-bulb-wet-bulb difference). The drying rate of prunes, on the contrary, has been found to be practically independent of the wet-bulb temperature, if the relative humidity is not above 40 per cent (if the dry-bulb-wet-bulb difference is not less than about 30 degrees F). At 60 per cent relative humidity, the drying rate of prunes is about two thirds of the rate at 40 per cent or below. Blanched cut fruits in their behavior are probably intermediate between vegetables and prunes.

Air velocity affects the drying rate, because the higher the velocity the thinner the rather stagnant air layer at the fruit surface, and the less the resistance to escape of vapor and acquisition of heat. Changes in air velocity have less influence upon the drying rate of slowly drying fruits, such as prunes and pears, than upon the drying rate of rapidly drying material, such as steam-blanched cut fruits. The relative effect of velocity is as follows :

| Velocity feet per minute | Relative drying rate, prunes | Relative drying rate, vegetables |
|-----------------------------|---------------------------------|-------------------------------------|
| 300 | 0.87 | 0.70 |
| 400 | 0.92 | 0.80 |
| 500 | 0.97 | 0.90 |
| 600 | 1.00 | 1.00 |
| 800 | 1.06 | 1.15 |
| 1,000 | 1.11 | 1.30 |

Small pieces dry more rapidly than do large ones, because the volume is smaller in proportion to the surface, and because the moisture within the piece does not have to travel so far to reach the surface.

In dehydration, since the air drops in temperature as it passes over the fruit, drying conditions vary from one end to the other in a commercial dehydrator. Conditions encountered in a typical counterflow prune tunnel are shown in

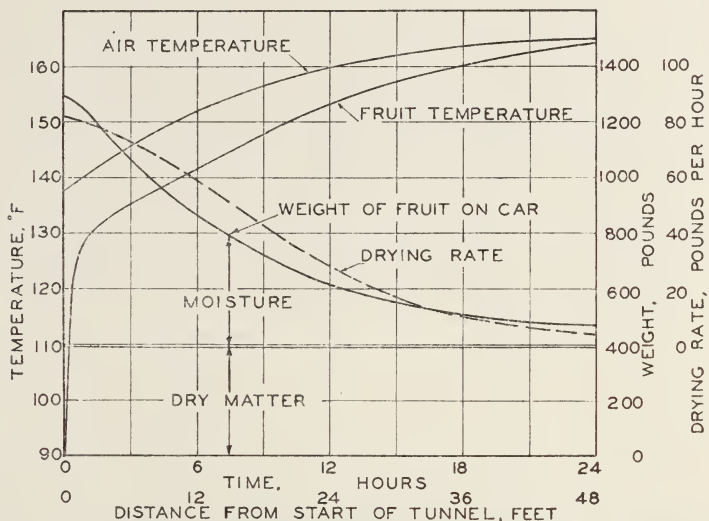


Fig. 14.—Average air and fruit temperatures, weight of fruit on a car, and drying rate, as a car of fruit proceeds through a counterflow dehydrator tunnel.

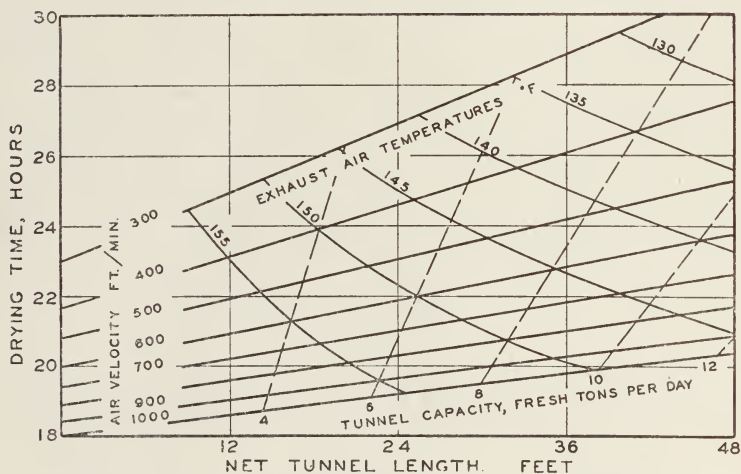


Fig. 15.—Relation between air velocity and drying time, with final exhaust air temperature also given, for counterflow dehydrators of different lengths. Initial air temperature 165° F, wet-bulb temperature not over 105°. Initial prune moisture content 70 per cent, final prune moisture content, 16.7 per cent. Prune size, dry count of 50 per pound.

figure 14. Most of the moisture is removed in the first few car positions. The air temperature changes most rapidly along the tunnel where the drying rate is greatest.

If the air velocity had been greater or the tunnel shorter, the air temperature at the fresh-fruit end would not have dropped so low, and the drying time

would have been shorter. An example of the relation between velocity, tunnel length, drying time, and final air temperature is given in figure 15, which is for a counterflow tunnel drying French prunes with a final size count of 50 per pound.

Fruit Temperatures during Dehydration.—High air temperatures give rapid drying rates and short drying times. But if the fruit temperature rises above a certain critical value for more than a very limited time, when the moisture content is low, the quality of the product is impaired and the storage life is reduced. Critical temperatures depend upon the kind of fruit and upon the moisture content. Although fruit temperature cannot be readily measured in commercial dehydrators, it can be estimated from the air temperature and the drying conditions.

When fruit is first moved into the relatively cool, humid end of a counterflow tunnel, its temperature rises rapidly until it is slightly above the wet-bulb temperature. Because of the high moisture content of the fruit at this point, the evaporation rate is fairly high if the relative humidity is not excessive. The fruit, therefore, remains considerably cooler than the air, until its moisture content has been materially reduced. As the car is moved through the tunnel, the air temperature is higher at each successive car position. When the fruit becomes drier, the evaporation rate becomes slower and, finally, the fruit temperature approaches that of the air. Typical temperatures in a counterflow tunnel are shown in figure 14. Special care must be taken to avoid exceeding the critical temperature near the end of dehydration, and to remove the fruit before its moisture content drops so low that its susceptibility to heat damage materially increases. Maximum air temperatures for typical counterflow tunnel operation are given as follows :

| Product | Maximum recommended air temperature, °F |
|-------------------------------|--|
| Apricots | 155* |
| Freestone peaches | 155* |
| Clingstone peaches | 160* |
| Nectarines | 155* |
| Pears | 140* |
| Golden-bleached raisins | 150 |
| Black Mission figs..... | 140 |
| Prunes | 165 |

* These figures to be used only if the fruit is dried to a moisture content not below 25 per cent.

In two-stage dehydration, the air temperature at the hot end of the primary parallel flow tunnel can be considerably higher than the values given above. The fruit is much cooler than the air, because of the high evaporation rate. Moreover, because of its high moisture content, it is not so susceptible to heat damage.

Air Flow.—Air is drawn in by the fan and then forced through the tunnel where it passes between the trays, over and around the fruit, and out of the tunnel. In some designs the furnace is installed before, in others after, the fan. As the air flows through this circuit, pressure losses result from changes in air velocity and direction, and from friction by contact with the sides of the tunnel, trays, and fruit.

In dealing with air flow, dehydrater performance, and friction losses, to attempt measurement of the actual velocities at all points adjacent to the fruit on the trays within the tunnel is seldom feasible. It is more practicable to measure the total air flow through the tunnel, bearing in mind that, with a given total air flow, the performance will vary with the tray spacing, tray loading, and side and top clearances. The air velocity over the fruit will be consistently higher than that in the free tunnel cross section.

Air velocities can be measured by the pinwheel anemometer, the balanced-vane impact instrument called the velometer, or the impact tip called the Pitot tube, which is read with a manometer or diaphragm chamber (fig. 16). In using any of these instruments to find regions where the flow is uniform enough to give steady and representative readings is sometimes difficult.

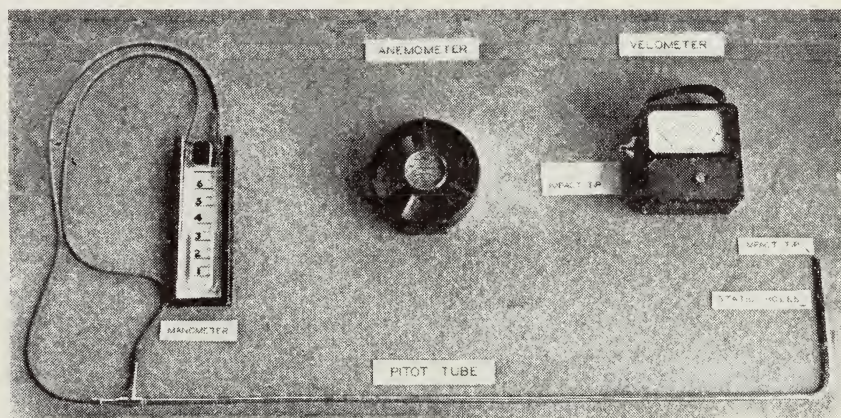


Fig. 16.—Instruments for measuring air velocities.

For measuring the total volume rate of flow (cubic feet per minute passing through the tunnel) the pinwheel anemometer has the advantage of giving an average reading. The recommended procedure is to move the instrument at a uniform, slow speed, in a traverse which will cover the entire cross section of the tunnel, at a point at least 2 feet from the downstream face of the last truck. Care must be taken to avoid speeding up the traverse, or dwelling in regions of high or low velocity, particularly at the walls or ceiling. The total air flow is found by multiplying the average velocity so obtained by the cross-sectional area of the tunnel. To investigate the uniformity of flow, the area can be divided into sections which can be traversed separately.

For taking instantaneous readings at particular points, the velometer is useful. Variations of velocity across the tunnel and pulsations of flow make the averaging of results difficult, but the instrument is helpful in exploring quickly the uniformity of flow.

Since a Pitot tube shows a differential of only $\frac{1}{16}$ inch of water at a velocity of 1,000 feet per minute, it is not well adapted for dehydrater-tunnel measurements.

Air Pressures and Friction Losses.—The air pressures which are developed in dehydraters are only a fraction of a pound per square inch. Conventional

pressure gauges are not suitable for measuring these low pressure differences. Installation of a manometer to measure the pressure within a duct (the pressure difference between the inside and outside of the duct) is shown at A in figure 17. The pressure connection must be made carefully at the duct wall, with the face of the tube opening parallel to the direction of air flow, and free from any projections or burrs. With a vertical water-filled manometer, the pressure is read from the difference in the levels in the two legs of the tube, as inches of water. Since a column of water 1 inch square and 1 inch high

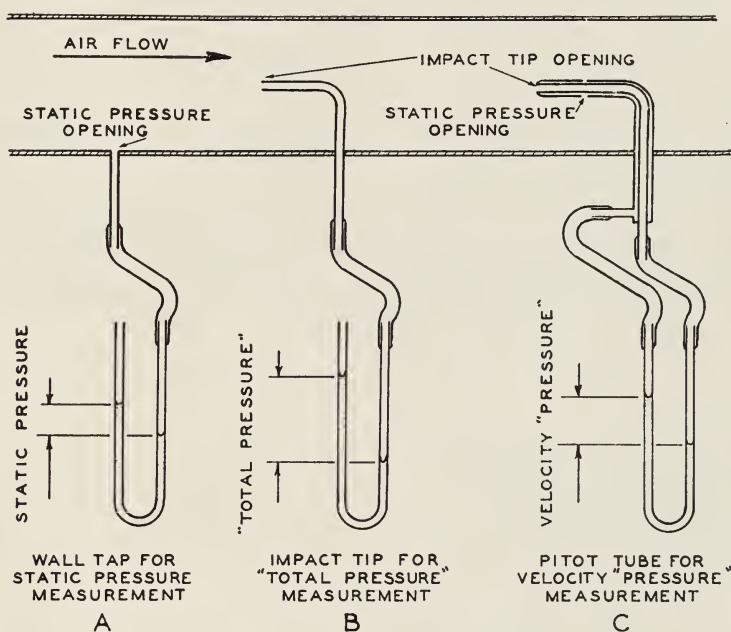


Fig. 17.—Installation of tubes for measuring air pressure.

weighs 0.0361 pound, an inch of water is equal to 0.0361 pound per square inch. In the measurement of air flow, it is customary to express pressures directly in inches of water rather than in pounds per square inch.

Energy is required to put air in motion, that is, to give it velocity. It is convenient to express the velocity of air in feet per minute, and the velocity or kinetic energy in terms of the equivalent pressure in inches of water. The energy related to velocity is

$$P_v = \left(\frac{V}{4,005} \right)^2 \times \frac{D}{0.075},$$

in which

P_v = Pressure equivalent of velocity energy, inches of water

V = Average velocity, feet per minute

D = Density of air, pounds per cubic foot.

For example, when air of a density of 0.06 pound per cubic foot is drawn through an opening, where it acquires a velocity of 2,000 feet per minute, the

velocity energy becomes $\left(\frac{2,000}{4,005} \right)^2 \times \frac{0.06}{0.075}$, or 0.20 inch of water.

Velocity energy is dissipated by turbulence resulting from sudden changes in direction of air flow, and by changes in the size of the duct system through which the air flows. Sharp turns and restrictions in the dehydrator should be avoided as much as possible. The performance of some poorly designed dehydrators could be considerably improved by increasing the area of air supply and exhaust openings.

Friction losses are unavoidably incurred in moving air. The losses are proportional to the square of the velocity, and to the ratio of the area of the surfaces contacted to the cross-sectional area of the passageway. Friction also depends upon the roughness of the surfaces. In the tunnel, where additional losses are caused by the continual change in velocity and direction as the air passes over and around the fruit, the pressure drop will vary greatly with the product and the tray loading. When trays are overloaded, so that the free space between them is reduced, the area through which air can flow is greatly restricted, and the air flow reduced.

Dehydrator-tunnel friction factors can be conveniently used when expressed as average pressure drop in inches of water per foot of tunnel length for an average air velocity of 600 feet per minute in the whole tunnel cross section. Friction factors for counterflow tunnels, based on observations by Moses, Guillou, Lorenzen, and Perry¹⁵ are as follows:

| Type of load | Friction factor |
|--|-----------------|
| Empty trays | 0.01 |
| Prunes, normal tunnel, 3 lb./sq. ft..... | 0.02 |
| Peaches, normal tunnel, 2½ lb./sq. ft..... | 0.018 |
| Grapes, normal tunnel, 3½ lb./sq. ft..... | 0.022 |
| Grapes, all green, 3½ lb./sq. ft..... | 0.040 |
| Grapes, all green, 5 lb./sq. ft..... | 0.065 |
| Grapes, normal tunnel, 5 lb./sq. ft..... | 0.025 |

The pressure drop through cars of fruit which is nearly dry, is not so great as through cars of fresh fruit. When it shrinks, fruit leaves more free space for air flow. The values in this table, designated for "normal tunnel," represent the average drop throughout a tunnel with the usual tray spacing, where fruit is fresh at one end and nearly dry at the other. For other operating conditions, appropriate friction factors would have to be found by tests. In using these factors,

$$\text{Pressure drop, in inches of water} = f \times L \times \left(\frac{V}{600} \right)^2.$$

In this expression,

f = friction factor, inches of water per foot of tunnel length, at a velocity of 600 feet per minute

L = tunnel length occupied by cars of fruit, in feet

V = average velocity in free cross section, in feet per minute

For example, the friction loss is to be found in a 12-car (36-foot) prune tunnel, which is 75 × 77 inches (40 square feet) in cross section, with an air flow of 30,000 cubic feet per minute. The average velocity from this data is

¹⁵ Unpublished data.

$\frac{30,000}{40}$, or 750 feet per minute. The pressure drop is then $0.02 \times 36 \times \left(\frac{750}{600}\right)^2$

or 1.14 inches of water.

Power Required to Move Air.—The power required by a fan is determined by the capacity, or air-volume rate in cubic feet per minute, the difference in air pressure between the inlet and discharge, and the fan efficiency. Although the pressures encountered seem very low, the energy for moving air to overcome them is by no means negligible. The power required by a fan is given as follows:

$$\text{Fan input horsepower} = \frac{Q \times P}{63.56 \times E}$$

in which

Q = air-volume rate, in cubic feet per minute

P = total pressure difference, including static and velocity pressure in inches of water

E = fan efficiency, in per cent

Thus a fan of 60 per cent efficiency, delivering 48,000 cubic feet per minute, against a static pressure of 1.25 inches and giving the air a velocity energy of

0.5 inch, will absorb $48,000 \times \left(\frac{1.25 + 0.5}{63.56 \times 60}\right)$, or 22 horsepower.

DRYING EQUIPMENT

The many different types of equipment used for drying foods have been described and illustrated by Rosseau (1939). Only a few of these, however, are suitable for fruit. Whole fruits and cut halves are usually dried at atmospheric pressure on trays placed in a forced air stream which provides the necessary heat energy and carries off the moisture. Sliced apples are also dried at atmospheric pressure, but in an air stream which moves upward through a bed of material by natural or forced convection. Other types of driers are used for special purposes.

Evaporators.—Apples are customarily dried in natural-draft evaporators, or occasionally in more modern dehydrators. Drying in old-style evaporators is slow and inefficient, and does not yield a uniform product; in recent years, however, material improvement has been effected by placing a propellor fan operated by a small motor in the roof vent of the natural-draft evaporator. These fans draw the air upward from the heater through layers of the fruit being dried on slatted floors, and force it out of the vents (fig. 18). The drying time may be decreased by one fourth, and the uniformity of the product greatly improved; however, it is still necessary to turn over the floor charge with shovels periodically during drying.

Some rather unsatisfactory attempts have been made to dry prunes in natural-draft kilns and rotary bake-oven driers. The natural-draft Oregon tunnel evaporator has found wide use in Oregon, because of the wet drying season. In recent years the performance of these has been materially improved by installation of fans, although they are not so efficient or economical as regular countercurrent-tunnel dehydrators.

Dehydrators.—The construction and operation of fruit dehydrators has been discussed in detail by Christie (1926), Nichols, Powers, *et al.* (1925), and Guillou and Moses (1943). Christie and Ridley (1923), Eidt (1938), Guillou (1942), and Van Arsdel (1942) have treated dehydrater design. A dehydrater which is built with roughly equal dimensions of length, width, and height is usually spoken of as a *cabinet*, or *compartment*, dehydrater. A dehydrater which is very long in proportion to width and height is called a *tunnel*.

Although forced draft and recirculation are used in most tunnel dehydraters, the methods of heating and conducting air flow through the plants vary considerably with the dehydration units designed by different engineers.

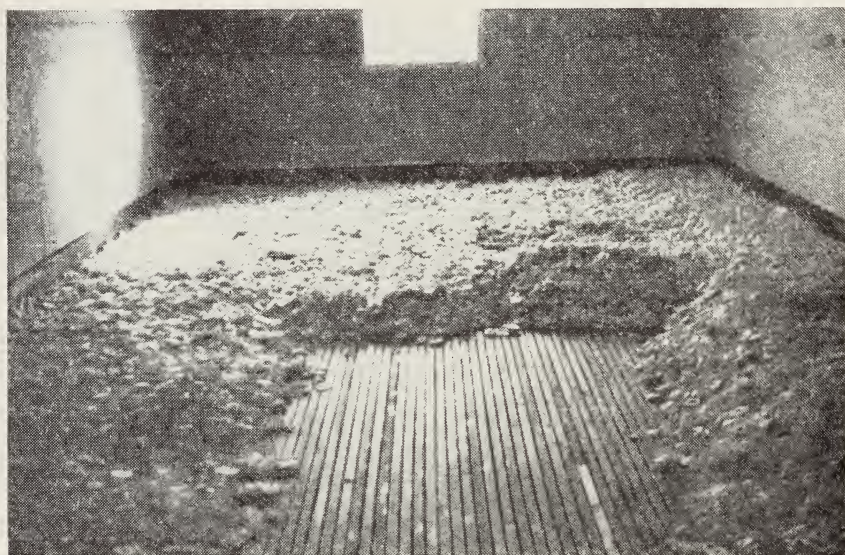


Fig. 18.—A slat-bottom kiln floor, partially loaded with freshly sliced apple rings. The air is drawn upward by a fan through the narrow openings between the slats.

The air to be passed over the drying fruit is heated by direct heat, direct radiation, or indirect radiation. By *direct heat* is meant the direct mixing of the products of combustion and the air without the intervention of furnace walls or flues. This can only be done by use of a fuel whose combustion products do not damage the fruit; natural gas is such a fuel. Oil is used in some plants, but a careless operator may easily damage a charge of fruit. It is impossible to use coal or wood in a direct-heat system. The advantages of direct heat are high fuel efficiency, 90 to 100 per cent furnace and 36 to 50 per cent over-all efficiency, low cost of installation and upkeep, and instantaneous temperature regulation through the absence of stored heat. The disadvantages of direct heat are the possible contamination of fruit by products of incomplete combustion and the necessity of a high-grade fuel.

Direct radiation refers to the systems in which heat from burning fuel is transferred through the furnace walls, flues, or radiators to the dehydrater air. This system offers the advantage of cleanliness and permits the use of any

kind of fuel. Since the furnace efficiency usually ranges from 60 to 90 per cent, the over-all efficiency of direct-radiation systems will be between 25 and 45 per cent. The disadvantages of direct radiation are greater cost of installation and upkeep, lack of instantaneous temperature regulation because of temporary heat storage, and lower fuel efficiency from stack losses.

Indirect radiation by means of steam or hot-water radiators is seldom used in California, where inexpensive, clean-burning fuels are available. The advantages of such a system are automatic regulation, freedom in choice of fuel used, and distribution of radiators where desired. The great disadvantages of indirect radiation are its expensive installation and upkeep and its low fuel efficiency. The furnace efficiency usually ranges from 60 to 70 per cent, and the over-all efficiency from 24 to 35 per cent.

TABLE 7
HEATING VALUES AND PRICES*

| Fuel | Approximate heating values | Comparison based on Diesel oil as unit | Prices | Relative cost based on Diesel oil as unit |
|------------------|----------------------------|--|--------------------|---|
| | <i>B.t.u.</i> | | <i>cents</i> | |
| Diesel oil..... | 133,000/gallon | 1 gallon | 6.25/gallon | 1.00 |
| Butane..... | 103,000/gallon | 1.29 gallon | 6.00/gallon | 1.24 |
| Natural gas..... | 1,100/cu. ft. | 121 cu. ft. | 50.00/1000 cu. ft. | 0.97 |
| Electricity..... | 3,412/kw.h. | 39 kw.h. | 1.5/kw.h. | 9.35 |

* After B. D. Moses, unpublished data.

Cost data on fuels are given in table 7. The efficiency of the several dehydrator types as given above must be considered in applying the relative cost data. Prices may vary from time to time in different regions.

The countercurrent, cross-flow, and center-inlet systems of air flow are most commonly used today, and the two-stage, parallel-counter system is being tried for drying grapes. Cabinet driers are occasionally used for batch operation.

Countercurrent Dehydrators.—Countercurrent tunnel dehydrators are the most widely used for fruits. Movement of cars of fruit through the tunnel is in opposite direction to the flow of air. The tunnel is generally about 6 $\frac{1}{4}$ feet wide, 7 feet high, and 40 to 60 feet long. Ordinarily, the tunnel length is sufficient to accommodate from 12 to 14 cars each holding from 25 to 28 trays, 6 \times 3 feet, or from 50 to 56 trays, 3 \times 3 feet. When the latter are used, 2 tray stacks are made on each car. The use of double cars, each holding two stacks of 6 \times 3 feet trays, is not recommended; the product dries too unevenly and the weight of the cars makes them too difficult to handle. The loaded cars enter at the cool- and moist-air exhaust end of the tunnel and move forward toward the hot end at 1- to 2-hour intervals, their movement being dependent on the product and the rate at which it dries.

Air is heated in a chamber adjacent to the drying tunnel. The heating chamber is usually located at one side of or above the drying tunnel. Air is drawn from the heating chamber and forced through the drying tunnel. A considerable quantity of the air may be recirculated.

Countercurrent tunnel dehydrators are satisfactory for slow-drying prod-

ucts, such as prunes, grapes, pears, and peaches. If they are used for apples, however, the tunnel load must be decreased, or the air flow and heat supplied in the drying tunnel must be increased. A typical countercurrent tunnel dehydrator is illustrated in figure 19.

Cross-flow Dehydrators.—In the cross-flow, or combination compartment and tunnel, arrangement is such that air flow is transverse to the axis of the tunnel.

Since the air can be reheated in the side chambers, or ducts, after a short passage through the trays, operation is possible at a low air velocity without

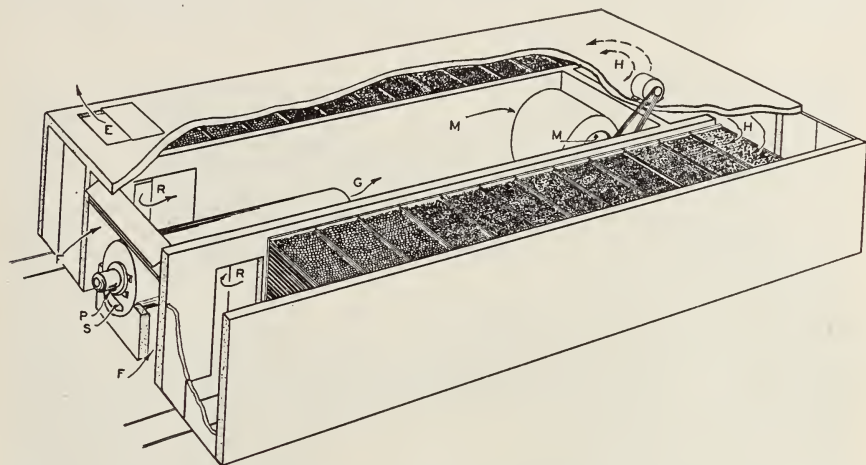


Fig. 19.—Double-tunnel, counterflow, direct oil-fired dehydrator with centrifugal fan: *E*, exhaust air; *F*, fresh air; *G*, gases heated in furnace; *H*, hot air delivered by fan to tunnels; *M*, mixture of fresh air, gases heated in furnace, and recirculated air entering the fan; *P*, primary fresh air for initiating combustion in the furnace; *R*, recirculated air; *S*, secondary fresh air for completing combustion in the furnace.

an excessive temperature drop. This possibility, which would permit good performance with low fan power, has not always been realized in practice. Some of the older and larger units have been quite difficult to control.

Recently Guillou and Moses (1943) presented plans, construction details, and operating instructions for a modified type of cross-flow dehydrator. It is inexpensive to construct and efficient to operate. The general plan is so flexible that the possible size range is wider than for many other designs. Units already in existence vary in size from one built to accommodate the fruit from a 6-acre prune orchard to another to care for the fruit from a 60-acre orchard.

The Guillou and Moses dehydrator is shown in figure 20. Heated air is drawn from a furnace room by a fan and is forced into a chamber, from which it flows across trays of fruit into an air duct. From the air duct the air is reversed and flows across the trays of fruit of a higher moisture content, a controlled portion being discharged through a door, while the remainder returns to the furnace room. The draft of the fan draws fresh air partly through the furnace and partly through openings adjacent to the furnace.

As will be noted in figure 20, a large volume of air passes along a short path at a high velocity through the wetter fruit and at a low velocity through the

fruit that is partially dried. According to Guillou and Moses, this type of air movement provides the following advantages:

1. The moderate air pressure required to move the air along a short path through the fruit may be provided by an inexpensive fan and a small motor. Units up to 8 tons per day green capacity can use a 5-horsepower motor. A single-phase motor of this size, or smaller, may usually be connected to the same electric meter as farm or household heating equipment, the user paying at the heating rate for the energy used by the motor.

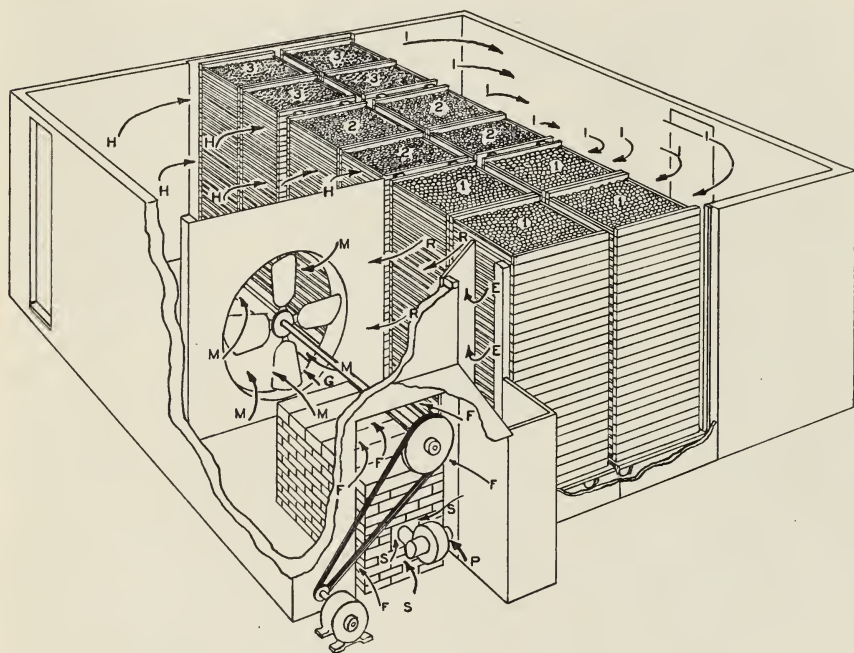


Fig. 20.—Cross-flow dehydrater, with axial-flow fan: 1, first position of fruit, when fresh; 2, second position of fruit, partially dried; 3, third position of fruit, nearly dried; *E*, exhaust air, escaping out of adjustable door; *F*, fresh air, entering beside furnace; *G*, gases heated in furnace; *H*, hot air delivered by fan to fruit in second and third positions; *I*, intermediate air passing from fruit in second and third positions to that in the first position; *M*, mixture of fresh air, gases heated in the furnace, and recirculated air entering the fan; *P*, primary fresh air for initiating combustion in the furnace; *R*, recirculated air passing from the fruit in the first position to the furnace chamber; *S*, secondary fresh air for completing combustion in the furnace.

2. The temperature drop through the charge is small. Heat is supplied rapidly to the fresh fruit by air moving at high velocity, and more slowly to the partly dried fruit by air moving at low velocity. This arrangement gives satisfactory drying time, with a moderate finishing temperature, and lessens the danger of caramelization and scorching. By slow, final drying, it reduces the differences in dryness caused by fruit of different sizes or of different initial moisture content.

3. One third of the fruit in the dehydrater may be changed at a time, the plant operating unattended between changes.

4. The fruit advancing through the dehydrator is subjected to a reversal of air flow, which tends to equalize drying.

Center-Inlet Dehydrators.—In the center-inlet tunnel the air flow is so arranged that the highest air temperature is at the center of the drying tunnel. The tunnel may be straight, with the air flowing toward the ends from the center, or it may be U-shaped, with the air flowing from the bend in the U toward each end. In either case the fruit enters at a lower temperature and moves toward the hotter air at the center, reaching it after about half of the drying period is completed. Then the fruit moves past the center and finishes drying in air of progressively decreasing temperature. Since a good deal of the moisture is removed in the first section of the tunnel, the temperature drop in the second section is not very great. This arrangement was probably developed in an effort to avoid what was believed to be retardation of drying caused by case hardening. Although the system has been used rather extensively, it

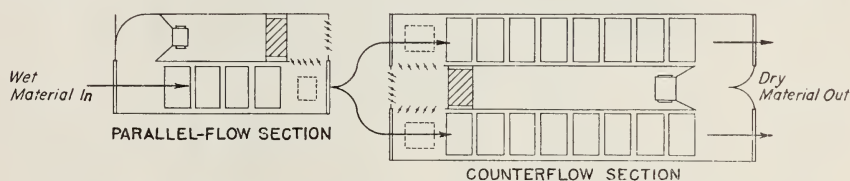


Fig. 21.—Two-stage dehydrator, consisting of two separate sections.
(Courtesy W. B. Van Arsdel, *Food Industries*, October, 1942.)

is more difficult to control than the simpler countercurrent type. Great care must be taken to avoid overheating in the center section; and drying may be found to be extremely slow toward the end.

Center-Exhaust or Two-Stage Dehydrators.—The center-exhaust system is the reverse of the center inlet. Heated air enters at the two ends and circulates toward the outlet, which is usually located about one third of the tunnel length from the place where fresh cars enter. Moist material moves in the same direction as the air flow at the wet end and counter to the air flow at the dry end (see fig. 21). This dehydrator is particularly suitable for dehydrating fast-drying products, such as apples and blanched cut fruit. The rate of drying is faster than in a countercurrent tunnel and, according to Eidt (1938), the quality of apples dried in a two-stage dehydrator is superior to that of apples dehydrated in a countercurrent tunnel or an evaporator. The construction and operation of these two-stage dehydrators has been discussed by Eidt (1938). In some instances two tunnels are used as two-stage driers. The two-stage system has been tried satisfactorily with grapes in a few plants.

Cabinet Dehydrators.—While the tunnel is best suited to continuous operation, the cabinet can be adapted to batch operation. It is thus used for intermittent operations in small plants. For the best quality of product, capacity, and economy, the air temperature and the amount of recirculation must be adjusted as drying proceeds. Beavens (1944) has given details of construction and operation of cabinet dehydrators. The method is less efficient and requires more labor than a tunnel dehydrator of equal capacity.

Conveyor Dehydrators.—In this drier, an endless belt is used to carry the fruit through the tunnel. The advantage is continuous operation and low labor

cost, but the disadvantages are high cost of installation and limitation to relatively dry products. Conveyor driers are used to reduce the moisture content of sun-dried raisins sufficiently before cap-stemming. In at least one instance a conveyor drier was used effectively to complete the drying of golden-bleached and Valencia raisins after their removal from a tunnel dehydrater; this additional operation reduced the time required in the tunnel dehydrater.

Vacuum Dehydraters.—These driers, described by Havighorst (1944) are used commercially only for reducing the moisture content of *dried fruits* to a

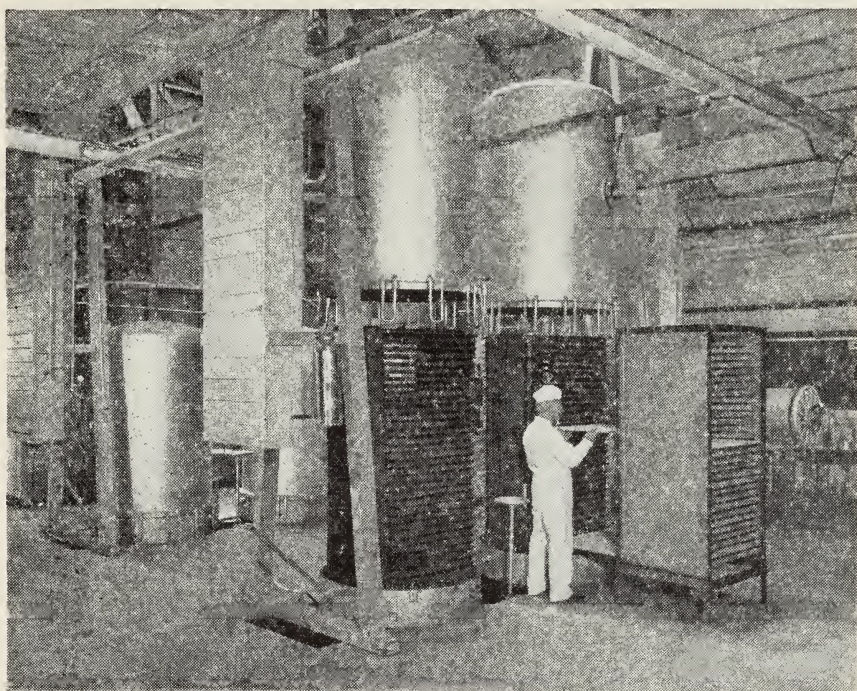


Fig. 22.—Vacuum tray dehydrater. (Courtesy of Vacudri Corporation, Emeryville, Calif.)

lower level (1 to 3 per cent) in the preparation of “nuggets,” “powders,” and “ribbons.” Various designs and arrangements are in use. Installation costs are high and experience in operation is necessary in order to secure the most satisfactory results. One design of vacuum drier used for preparing fruit nuggets is shown in figure 22.

Drum Driers.—Drum driers are used to convert cranberry pulp into flakes. The driers may be single or double drums, operated under atmospheric pressure or vacuum. The single drum, atmospheric type, is used for cranberries. Fruit puree of a definite consistency is spread uniformly on the outer surface of a revolving steam-heated drum; the speed of rotation of the drum is such that the product is dried by the time the adhering film has moved to position for removal.

Furnaces.—For direct-heat dehydraters, the furnace must be carefully designed and installed, especially if oil is to be burned. For gas, there are

several types of burners which can fire directly into the heating chamber (see fig. 23). However, a refractory firebox partially surrounding the burner helps to maintain good combustion with a low flame.

Oil burners should be placed to fire into firebrick-lined tubes with two checkerbrick baffles, as shown in figure 24. Some builders, although skilled in erecting furnaces for boilers, have installed units which are not suited to dehydraters.

The furnace tube for an oil burner must be large enough to permit complete combustion within, but not so large that its temperature is too low with a light

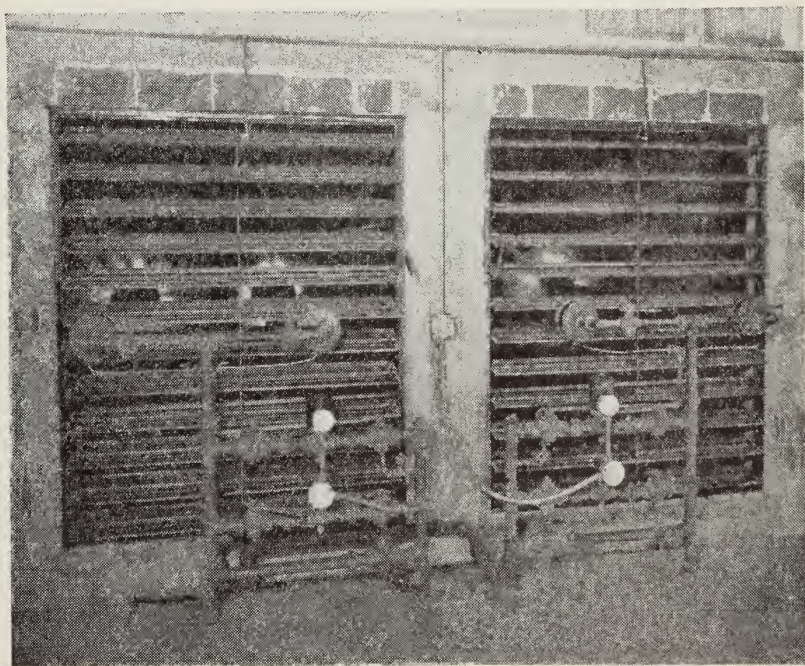


Fig. 23.—Full-view picture of the end of the furnace showing the automatic gas burners in operation and the other automatic controls on the outside of the heat chamber which operates them. (Courtesy of the Fresno Dehydrating Company.)

fire. From $\frac{1}{5}$ to $\frac{2}{5}$ of a gallon of oil can be burned per hour, per cubic foot of furnace volume. A 36-inch diameter tube can be used for 20 gallons per hour, while a 60-inch tube is needed for 50 gallons per hour. The length of tube up to the first baffle should follow the recommendations of the burner manufacturer. The first baffle insures a hot firebox with a low flame, whereas the second baffle provides a hot refractory-lined space in which combustion is completed with a high flame. To avoid undue restriction of air flow through the furnace, the baffles must be built as open as possible without sacrificing their strength.

The flow of air must be great enough to keep the furnace temperature below the softening point of the firebrick. In boiler furnaces, or indirect-fired dehydraters, where a large part of the heat released by combustion is absorbed by relatively cold heat-exchange surfaces, maximum efficiency is secured with

an air supply only large enough to give complete combustion—about 15 per cent above the theoretical amount for gas or oil. In a dehydrater with direct heat, however, the furnace gases warm the dehydrater air by mixing with it, and dehydrater efficiency is not reduced by having a considerable fraction of the fresh air enter through the furnace. Moreover, the furnace, transferring

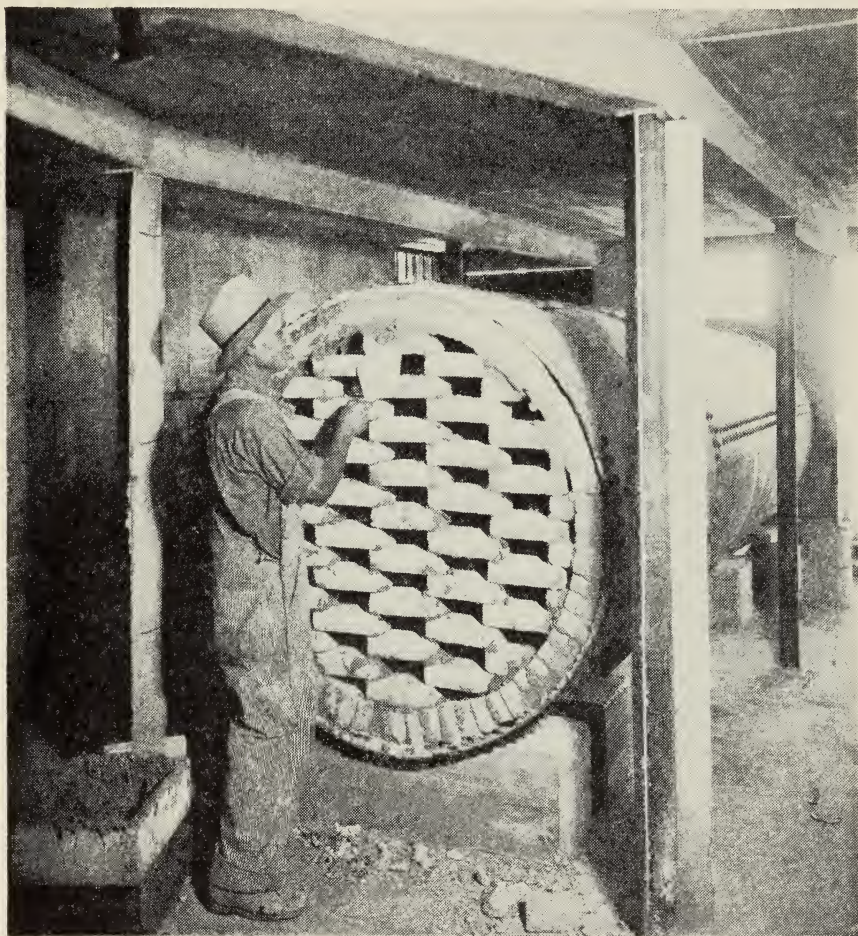


Fig. 24.—Construction of a terminal checkerbrick baffle in a furnace tube for a direct-heat oil burner. (Courtesy of the Fresno Dehydrating Company.)

practically no heat by radiation to cold exchange surfaces, would quickly rise above the softening point of the brick if only 15 per cent excess air were provided. The air supply must be sufficient to dilute the burned gases enough to keep the temperature at the maximum firing rate below $2,500^{\circ}\text{F}$ in furnaces built of high-grade firebrick. This requires about 2,700 cubic feet of air per gallon of oil, nearly twice the requirement for a boiler furnace. The secondary air openings through the furnace front must be ample, because the furnace should operate with a low draft in order to economize on dehydrater fan power.

Fans.—For any design of fan, there is theoretically a particular size and speed which will result in operation at the maximum efficiency inherent in the design for each given combination of static pressure and volume. If there were no limitation of size, speed, or initial cost, the most efficient type of fan would be selected. In practice, however, it is found that certain types of fans are more suitable than others for tunnel dehydraters.

Until recently, centrifugal fans of the backward-curved multiblade type (fig. 25) were most widely used. With improvement in design, and a trend

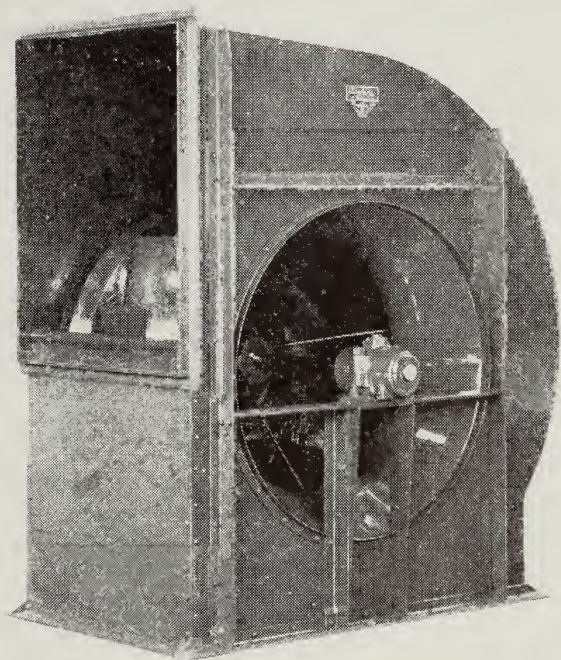


Fig. 25.—A single-width, single-inlet, centrifugal fan with backward-curved blades. (Courtesy of the Western Blower Company.)

toward shorter tunnels, axial-flow pressure fans (fig. 26) have been installed with success in some modern dehydraters. The peak efficiencies of some of the centrifugal fans are higher than those of most axial-flow fans. Because of their greater initial cost and their bulk, however, somewhat smaller than optimum sizes of centrifugal units have in some instances been installed for short seasonal operation, with the result that the maximum efficiency has not always been realized. When the static pressure to be overcome has been overestimated, the fans have been connected to operate at an unnecessarily high speed, and the power required has been excessive.

Three types of axial-flow fans are now in use: flat, wide-blade propellers, aerofoil-section narrow-blade propellers, and air screws in which the projected area of the blades covers a large proportion of the fan circle. The wide-blade

air screw is relatively efficient and quiet, but highest in initial cost. Some aerofoil propellers are efficient, but noisy at high speeds. The flat, wide-blade propeller is likely to have a lower efficiency than the other two, but is lowest in initial cost. A large-diameter hub is an aid to securing high efficiency in most designs of axial-flow fans intended for operation against appreciable static pressures.

The fan must be able to deliver the required volume of air, in cubic feet per minute, against the static pressure caused by the friction and turbulent losses

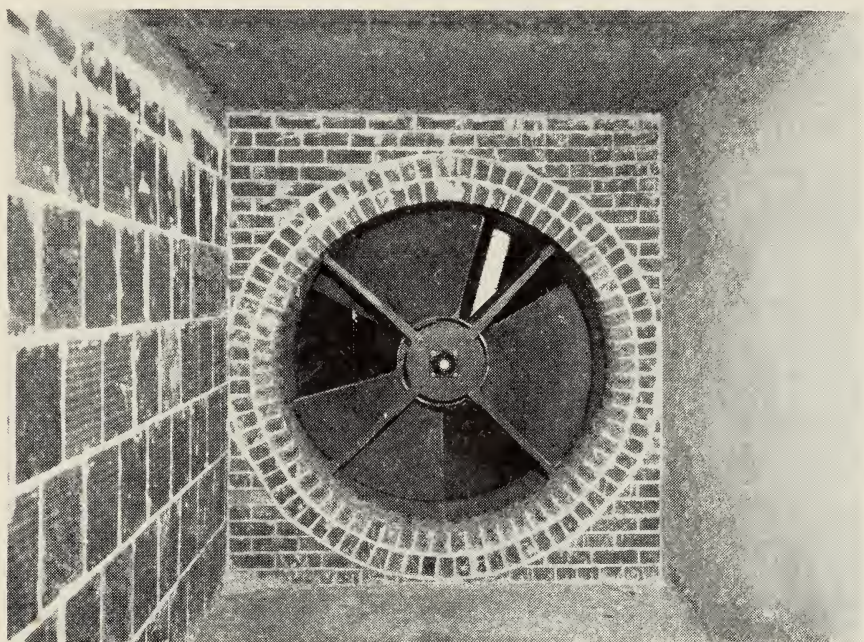


Fig. 26.—Air chamber and axial-flow fan. (Courtesy of the Fresno Dehydrating Company.)

of the heating chamber, tunnel, and air openings. Counterflow-tunnel friction losses, based on the friction factors shown on page 49 are illustrated by the data presented in table 8. This table is based on an air velocity of 600 feet per minute in a 12-car (36-foot working length) tunnel, with the usual tray design. The designation "normal tunnel" indicates that the fruit has the usual range of size on the trays corresponding to the progressive change from fresh to dried fruit. Higher velocities may be desired in dehydrators intended to handle those cut fruits that dry rapidly, and they will entail greater friction losses than those indicated in table 8. In addition to the friction loss in the tunnel, the pressure drop in the heating chamber and in the turns entering and leaving the tunnel will be about $\frac{1}{4}$ inch of water. With inlet air openings which permit an air velocity of say 2,000 feet per minute (24 square feet for the 48,000 cubic feet per minute supplied to a double tunnel), an additional pressure of $\frac{1}{4}$ inch of water is required to bring the air up to the speed with which it enters the unit. Thus, the fan must be able to operate against a static

pressure at least $\frac{1}{2}$ inch greater than the friction loss in the tunnel itself. The fan horsepower required to deliver 24,000 cubic feet per minute against the static pressures listed, is also given in table 8, based on a fan static efficiency of 50 per cent. In a fixed installation, if a fan were selected to operate against the highest pressure shown in the table, its power requirements would be greater than if it were selected to operate against the lower static pressures.

The operating characteristics of a typical centrifugal fan are illustrated in figure 27; those of an axial-flow fan in figure 28. In these figures, the relation between the static pressure encountered and the volume to be delivered is given for a moderate fan speed by curve 1, and for a high fan speed by curve 2. The resistance offered by the dehydrater is given by curve 3 for a tunnel with normally loaded cars of prunes, and by curve 4 for a tunnel with heavily

TABLE 8

AIR FRICTION AND FAN OPERATING PRESSURES AND HORSEPOWER IN A TWELVE-CAR TUNNEL AT 600 FEET PER MINUTE AIR VELOCITY*

| Commodity, tray loading, and condition | Tunnel friction loss (inches of water) | Fan static pressure (inches of water) | Fan horsepower in a single tunnel |
|--|---|--|-----------------------------------|
| | <i>inches</i> | <i>inches</i> | <i>hp.</i> |
| Prunes—3 lb./sq. ft., normal tunnel..... | 0.72 | 1.22 | 9.2 |
| Thompson Seedless grapes—3½ lb./sq. ft., all green..... | 1.44 | 1.94 | 14.6 |
| Thompson Seedless grapes—3½ lb./sq. ft., normal tunnel.... | 0.80 | 1.30 | 9.8 |
| Thompson Seedless grapes—3½ lb./sq. ft., all dry..... | 0.40 | 0.90 | 6.8 |

* Based on 24,000 cu. ft. per minute and a fan efficiency of 50 per cent.

loaded grape cars. With moderate speed and normal resistance, the static pressure encountered and the volume delivered are shown by point *A*, and the power required is indicated by point *a*. Point *B* gives the volume and static pressure for moderate speed and high dehydrater resistance, and point *b* gives the power required for this condition. With high fan speeds, the corresponding pressures and volumes are given by points *D* and *C*, the power requirements are indicated by points *d* and *c*. It can be seen that if the fan were selected to deliver air against an anticipated high pressure, point *C*, but instead encountered only the lower resistance, the actual operation would be given by point *D*. If only the volume represented by point *C* were needed, the power could be reduced from that of point *c* to point *a*, by reducing the fan speed to give the operation at point *A*.

Tunnel-Dehydrater Operation.—The drying characteristics of most fruits which are dehydrated are known only in a rather general way. Each operator must ascertain the conditions of his own plant which will give the best combination of high quality, capacity, and efficiency. For a particular plant, the conditions may differ somewhat from general recommendations.

For a given tunnel length, initial air temperature, and air velocity, the time of drying and final air temperature are fixed by the characteristics of the material being dried. This is illustrated for prunes in figure 15. With a slow-drying material, the average temperature drop per foot of tunnel length is small, so that long tunnels can be used. If slow-drying materials are to be dried

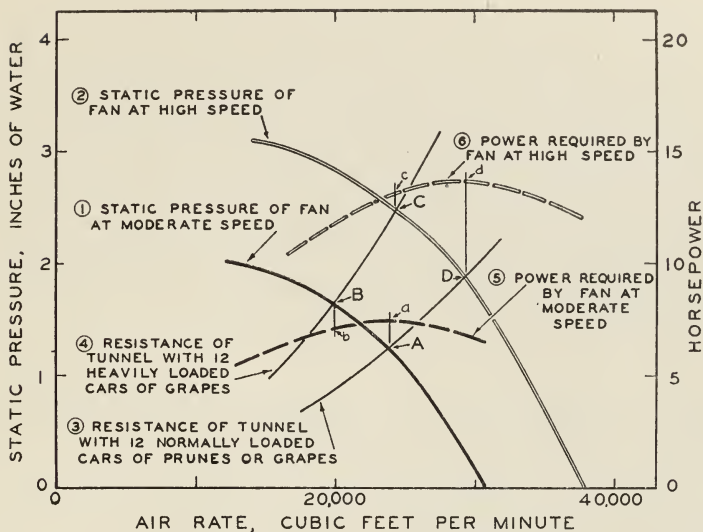


Fig. 27.—Characteristics of a backward-curved blade centrifugal fan.

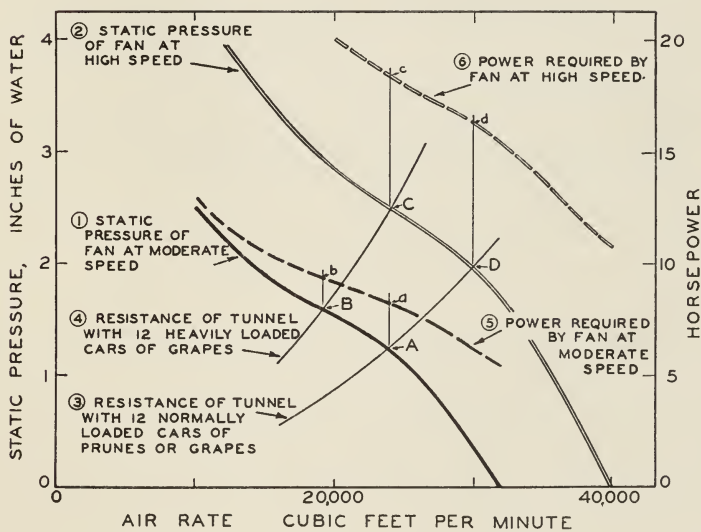


Fig. 28.—Characteristics of an axial-flow fan.

in short tunnels, the temperature drop will be small and the efficiency will be low unless recirculation is used.

With a fast-drying material, the temperature drop per foot of tunnel length is large, and recirculation may not be practical even in a moderately short tunnel. If a fast-drying material is to be dried in a long tunnel, the tunnel should not be filled with cars, or the drying conditions at the cool, humid end will be unsatisfactory.

A very helpful indication of the operating conditions within a tunnel can be obtained from observation of the difference between temperatures of dry- and wet-bulb thermometers at the cool, or fresh fruit, end. Each time a car of fresh fruit is introduced, the final air temperature drops considerably, for the fruit on this car is relatively cold. In addition, each of the cars which has been moved ahead in the tunnel contains fruit that is not so dry as that on the car previously in the same position, and the evaporation rate throughout the tunnel is greater than before the recharge. This also causes a greater temperature drop in the tunnel and a cooler final air temperature. The temperature gradually rises, as the fruit on each car becomes drier, until again it is time to remove the driest car and put in another fresh one.

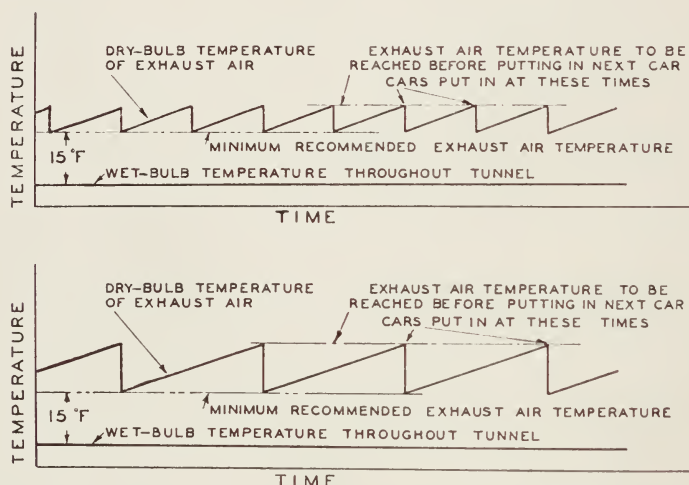


Fig. 29.—Exhaust air temperatures, at the end of single-car and double-car dehydrator tunnels.

If the drying rate is slower and the drying time longer than anticipated, the cold-end air temperature will be found to be a little lower each time a new car is introduced. This is a sign that the tunnel is being overloaded. If this happens, the time interval between cars should be lengthened, the amount of recirculation reduced, or the air velocity increased. If an adjustment is not made, the cars will not be ready to be taken out when they reach the front end of the tunnel, and the number of cars in the tunnel—if it is not already filled—will be increased. The result at the cool end is that, with cooler and more humid air, the drying rate of the fresh cars will be retarded and soon the tunnel will be filled with cars, of which only the first few will be drying satisfactorily. If this condition is anticipated from observation of cool-end temperatures, poor operating conditions can be avoided. With appropriate attention, the operator can learn for each commodity the dry-bulb-wet-bulb difference which must be attained before the next car should be introduced.

An approximate rule is that, after introducing a fresh car, the dry-bulb temperature should be 15 degrees F higher than the wet-bulb temperature. The extent to which the dry-bulb temperature should be allowed to rise before

a new car is put in depends upon the nature of the product, the air velocity, and the fraction of the tunnel load which one car comprises.

Typical cool-end air temperature changes are illustrated in figure 29 for dehydration of peaches on single and on double cars. With single cars, the air temperature was found to drop about 7 degrees F when a fresh car was introduced. In order to have a 15-degree difference afterward, a 22-degree difference between dry- and wet-bulb temperatures was necessary before a fresh car was put in. With double cars, a 14-degree temperature change occurred each time a new car was introduced; it was therefore necessary to have a 29-degree difference between dry- and wet-bulb temperatures before putting in another car. During much of the latter period, the air was not effectively used, but the new car could not have been introduced sooner or poor drying conditions would have resulted.

Another disadvantage of double cars is the appreciable difference between the drying rate at the front and at the back sides of the trays. Furthermore, because of the great weight, handling is so difficult that an extra man is needed to move the double truck—yet he is frequently idle.

In starting the operation of a tunnel, some modification must be made from the normal operating schedule. It is highly undesirable to put several cars of fresh fruit into one tunnel on starting; the evaporation rate from a car of fresh fruit in an empty tunnel is great, and the drop in temperature of the air passing through the car is high. For example, if 1 car, 6 × 6 feet in size, containing blanched clingstone peaches is introduced in an empty tunnel, with an air velocity of 1,000 feet per minute and a temperature of 155° F, there will be an initial temperature drop of almost 30 degrees. If more than 3 or 4 single cars are introduced at once, the air moving past the last car will be nearly saturated. This is indicated by the fact that the dry-bulb temperature will be nearly as low as the wet-bulb temperature. Thus, little evaporation can occur from the last car which has entered until the first cars have lost a considerable part of their moisture; at this time their evaporation rate will be less and the air reaching the last car will be warmer and less humid. The lower the air flow, the smaller is the number of fresh cars which can be introduced in an empty tunnel without excessively building up the humidity.

One procedure in starting is to introduce cars at a regular schedule, with the hot-end air temperature at first adjusted to about the average cold-end temperature to be found with steady operation. Each time a new car is put in, the hot-end temperature is raised until the normal operating temperature is reached. The proper temperatures for the hot-end air can be selected from an air-temperature curve like that shown in figure 14 (p. 46). The first car under this procedure will dry in just a little less than normal time, for it was subject to approximately normal tunnel temperatures, although the humidity of the air passing by it was low during its entire drying period. The first car of an unfamiliar product should be examined as the predicted drying time is approached, in order that the drying schedule can be modified if necessary.

The other procedure on starting is to keep the hot-end air at normal operating temperature and to introduce cars more frequently at first than would be done under the normal schedule. The latter procedure is simpler and requires less supervision than the former method.

LITERATURE CITED

ALLEN, F. W.

1937. Apple growing in California. California Agr. Exp. Sta. Bul. 425:1-95. Revised.

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS.

1945. Heating, ventilating, air-conditioning guide. 1146 p. American Society of Heating and Ventilating Engineers, New York, N.Y. (Published annually.)

BEAVENS, E. A.

1944. Cabinet dehydraters suited to small scale operations. Food Indus. 16(1):70; (2):90; (3):75.

BISSON, C. S., H. W. ALLINGER, and H. A. YOUNG.

1942. Some factors affecting the burning of sulfurs used in sulfuring fruits. Hilgardia 14(6):361-72.

CALDWELL, JOSEPH S.

1923. Evaporation of fruits. U.S. Dept. Agr. Bul. 1141:1-62.

CARDIFF, IRA D.

1937. Observations with reference to arsenic on apples and other foods. Washington State Hort. Assoc. Proc. 33:153-68.

CHRISTIE, A. W.

1924. California dehydration statistics for 1923. West. Canner and Packer 16(3):44, 45.

1926. The dehydration of prunes. California Agr. Exp. Sta. Bul. 404:1-47. (Out of print.)

CHRISTIE, A. W., and G. B. RIDLEY.

1923. Construction of farm dehydraters in California. Amer. Soc. Heating and Ventilating Engin. Jour. 29:687-716.

CONDIT, IRA J.

1941. Fig culture in California. California Agr. Ext. Cir. 77:1-67.

CRAFTS, A. S.

1944a. Some effects of blanching. Food Indus. 16(3):184-85.

1944b. Cellular changes in certain fruits and vegetables during blanching and dehydration. Food Res. 9:442-52.

CRAWFORD, L. A., and EDGAR B. HURD.

1941. Types of farming in California analyzed by enterprises. California Agr. Exp. Sta. Bul. 654:1-128.

CRUESS, W. V.

1919a. Evaporaters for prune drying. California Agr. Exp. Sta. Cir. 213:1-30. (Out of print.)

1919b. Lessons for prune growers from the September rains. California State Commission Hort. Mo. Bul. 8:51-60.

1921. Salvaging rain-damaged prunes. California Agr. Exp. Sta. Cir. 212:1-11. (Out of print.)

1938. Commercial fruit and vegetable products. 798 p. McGraw-Hill Book Co., New York, N.Y. (New edition in press.)

1943. Prune dehydration experiments. Fruit Prod. Jour. and Amer. Vinegar Indus. 22:324-25, 330.

CRUESS, W. V., A. W. CHRISTIE, and F. H. C. FLOSSFEDER.

1920. The evaporation of grapes. California Agr. Exp. Sta. Bul. 322:419-71. (Out of print.)

CRUESS, W. V., H. FRIAR, E. G. BALOG, and PHYLLIS VAN HOLTEN.

1944. A new method of sulfuring fruit for drying. Fruit Prod. Jour. and Amer. Food Manuf. 24(4):103; 121.

CRUESS, W. V., and G. MACKINNEY.

1943. The dehydration of vegetables. California Agr. Exp. Sta. Bul. 680:1-76.

DAVIS, L. D., and W. P. TUFTS.

1941. Pear growing in California. California Agr. Ext. Cir. 122:1-87.

EIDT, C. C.

1938. Principles and methods involved in the dehydration of apples. Canada Dept. Agr. Pub. 625 (Tech. Bul. 18):1-36.

- ESSIG, E. O., and W. M. HOSKINS.
1944. Insects and other pests attacking agricultural crops. California Agr. Ext. Cir. 87:1-197. Revised.
- FAIRHALL, L. T., and P. A. NEAL.
1938. The absorption and excretion of lead arsenate in man. U.S. Pub. Health Serv. Bul. 53:1231-45.
- FISHER, C. D., E. M. MRAK, and J. D. LONG.
1942. Effect of time and temperature of sulfuring on absorption and retention of sulfur dioxide by fruits. Fruit Prod. Jour. and Amer. Vinegar Indus. 21:175-76; 199-200; 217; 219; 237-38.
- FRIAR, H., and E. M. MRAK.
1943. Dehydration of huckleberries. Fruit Prod. Jour. and Amer. Vinegar Indus. 22:138-39.
- GEIGER, J. C., G. H. BECKER, and A. B. CROWLEY.
1936. Poisonous substances in foods, particularly spray residue on fruits and vegetables. Amer. Jour. Pub. Health 26:382-84.
- GUILLOU, R.
1942. Developments in fruit dehydrater design. Agr. Engin. 23:313-16.
- GUILLOU, R., and B. D. MOSES.
1943. Farm fruit dehydrater. University of California Agricultural Engineering and Agricultural Extension Farm Building Plan C-214:1-22. (Mimeo.)
- HALLER, M. H., E. SMITH, and A. L. RYALL.
1935. Spray-residue removal from apples and other fruits. U.S. Dept. Agr. Farmers' Bul. 1752:1-25.
- HANZLIK, P. J.
1937. Health hazards of chemo-enemies in contaminated foods. Sci. Monthly 44:435-39.
- HARTMAN, H.
1929. The Oregon apple washer. Oregon Agr. Exp. Sta. Cir. 92:1-8.
- HAVIGHORST, C. R.
1944. 1 per cent moisture attained by vacuum dehydration. Food Indus. 16(4):258-62.
- HENDRICKSON, A. H.
1937. Apricot growing in California. California Agr. Ext. Cir. 51:1-60. (Out of print.)
- HOFFMAN, M. B.
1937. Some results on washing cherries for removal of spray residue. Amer. Soc. Hort. Sci. Proc. 34:275-78.
- HOUGH, W. S.
1936. Spray residues and their removal from apples. Virginia Polytech. Inst. Bul. 302:1-20.
- HOWARD, W. L.
1947. Home fruit growing in California. California Agr. Ext. Cir. 117. (Revision in press.)
- HUSSEIN, A. A., E. M. MRAK, and W. V. CRUESS.
1942. The effect of pretreatment and subsequent drying on the activity of grape oxidase. Hilgardia 14(6):349-57.
- JACOB, H. E.
1947. Grape growing in California. California Agr. Ext. Cir. 116. (Revision in press.)
- JACOB, H. E.
1942. The relation of maturity of grapes to the yield, composition, and quality of raisins. Hilgardia 14(6):321-45.
- JACOB, H. E.
1944. Factors influencing the yield, composition, and quality of raisins. California Agr. Exp. Sta. Bul. 683:1-44.
- LOESECKE, H. W., VON.
1943. Drying and dehydration of foods. 302 p. Reinhold Publishing Corp., New York, N.Y.
- LONG, J. D., E. M. MRAK, and C. D. FISHER.
1940. Investigations in the sulfuring of fruits for drying. California Agr. Exp. Sta. Bul. 636:1-56.

MARSHALL, W. R., JR.

- 1942-43. The drying of foods. *Amer. Soc. Heating and Ventilating Engin. Jour.* 14:527-31; 588-91; 671-73; 724-28; 15:567-72; 637-41.

MRAK, E. M., C. D. FISHER, and B. BORNSTEIN.

1942. The effect of certain substances and pretreatments on the retention of color and sulfur dioxide by dried cut fruits. *Fruit Prod. Jour. and Amer. Vinegar Indus.* 21:297-99.

MRAK, E. M., and J. D. LONG.

1941. Methods and equipment for the sun-drying of fruits. *California Agr. Exp. Sta. Cir.* 350:1-69.

MRAK, E. M., H. J. PHAFF, C. D. FISHER, and G. MACKINNEY.

1943. Dehydration of fruits offers important wartime advantages. *Food Indus.* 15(4): 59-62.

NICHOLS, P. F., and A. W. CHRISTIE.

1930. Drying cut fruits. *California Agr. Exp. Sta. Bul.* 485:1-46. (Out of print.)

NICHOLS, P. F., RAY POWERS, C. R. GROSS, and W. A. NOEL.

1925. Commercial dehydration of fruits and vegetables. *U.S. Dept. Agr. Bul.* 1335:1-40.

OVERLY, F. L., J. L. ST. JOHN, E. L. OVERHOLSER, and K. GRAVES.

1933. Lead and arsenic spray residue removal from apples. *Washington Agr. Exp. Sta. Tech. Bul.* 286:1-83.

PHAFF, H. J.

1945. Aspects of sulfuring fruits for drying. *Modesto Dehydration Confer. Proc.* May 1, 1945. (Litho.)

PHAFF, H. J., G. L. MARSH, E. M. MRAK, and C. D. FISHER.

1945. New methods produce superior dehydrated cut fruits. Part II, Apricots. *Food Indus.* 17(5):517.

PHAFF, H. J., E. M. MRAK, R. L. PERRY, and C. D. FISHER.

1945. New methods produce superior dehydrated cut fruits. Part III, Clingstone peaches and pears. *Food Indus.* 17(6):634.

PHAFF, H. J., R. L. PERRY, and E. M. MRAK.

1945. New methods produce superior dehydrated cut fruits. *Food Indus.* 17(2):150.

PHILP, GUY L., and LUTHER D. DAVIS.

1946. Peach and nectarine growing in California. *California Agr. Ext. Cir.* 98:1-64. Revised.

PIERCE, DAVID E.

1942. Chemical engineering for production supervision. 232 p. McGraw-Hill Book Co., New York, N.Y.

ROBINSON, R. H., and M. B. HATCH.

1933. The removal of lead and arsenic spray residues from pears. *Oregon Agr. Exp. Sta. Bul.* 317:1-15.

1935. Spray residue information for the orchardist and fruit packer. *Oregon Agr. Exp. Sta. Bul.* 341:1-22.

ROSE, D. H., R. C. WRIGHT, and T. M. WHITEMAN.

1941. The commercial storage of fruits, vegetables, and florists' stocks. *U.S. Dept. Agr. Cir.* 278:1-52.

ROSSEAU, F.

1939. Dehydration equipment as applied to food processing. *Food Indus.* 11(1):687-702.

SHEAR, S. W.

1943. Deciduous fruit statistics as of January, 1943. Contribution from the Giannini Foundation of Agric. Econ. Rept. 83. (Mimeo.)

VAN ARSDELL, W. B.

1942. Tunnel dehydraters and their use in vegetable dehydration. Parts I, II, and III. *Food Indus.* 14(10):43-46; 14(11):47-50; and 14(12):47-50.

VEIHMAYER, F. J., and A. H. HENDRICKSON.

1943. Essentials of irrigation and cultivation of orchards. *California Agr. Ext. Cir.* 50:1-23. Revised.

WALKER, W. H., W. K. LEWIS, W. H. McADAMS, and E. R. GILLILAND.

1937. Principles of chemical engineering. 749 p. McGraw-Hill Book Co., New York, N.Y.

WIEGAND, E.

1924. Drying prunes in Oregon. *Oregon Agr. Exp. Sta. Bul.* 205:1-26.